Seasonal Bycatch Survey of the Georges Bank Scallop Fishery

Final Report

Prepared for the 2013

Sea Scallop Research Set-Aside

(NA13NMF4540011**)**

May 2015

Submitted By

Carl Huntsberger, Katherine Thompson, Megan Winton, Liese Siemann
Coonamessett Farm Foundation, Inc

In Collaboration with

Kevin Stokesbury, Steve Cadrin, Susan Inglis,
Gregory DeCelles, Crista Bank, Brooke Wright - SMAST
David Rudders- Virginia Institute of Marine Sciences
Roxanna Smolowitz- Roger Williams University

Coonamessett Farm Foundation, Inc

277 Hatchville Road
East Falmouth, MA 02536
508-356-3601 FAX 508-356-3603
contact@cfarm.org
www.coonamessettfarmfoundation.org

NOAA Grant Number: NA13NMF4540011

A. Grantee: Coonamessett Farm Foundation, Inc
B. Project Title: Seasonal Bycatch Survey of the Georges Bank Scallop Fishery
C. Amount of Grant: $630,576.66
D. Award Period: 03/01/2013 - 02/28/2015
E. Reporting Period: 03/01/2013 – 05/31/2015

2013 Seasonal Bycatch Survey Trips (NA13NMF4540011):

F/V Endeavor	April 27 – May 4, 2013
F/V Zibet	June 12 – 18, 2013
F/V Venture	July 26 – June 2, 2013
F/V Atlantic	September 9 – 14, 2013
F/V Regulus	October 26 – November 2, 2013
F/V Vanquish	December 10 – 18, 2013
F/V Horizon	January 15 – 22, 2014
F/V Liberty	March 8 – 13, 2014

Executive Summary:

Project Goals and Objectives:

- Examine the temporal and spatial impact on bycatch rates in the George's Bank scallop industry
- Optimize high scallop catch with low yellowtail flounder bycatch by understanding seasonal fish distribution and variation in scallop meat quality.
- Gear comparison of a New Bedford dredge vs turtle deflector dredge in regards to bycatch
- Investigate the general biology of scallops and bycatch species, specifically maturity, growth, and disease
- Evaluate the use of a seasonal dredge survey as a fisheries management tool

The data presented in this report is from funding year 2013 of the seasonal bycatch survey on Georges Bank in the sea scallop fishery. This bycatch survey has been operating over a similar fixed grid since October 2010 and has been modified and adapted to address current management concerns.

In 2010 research began as a gear testing project occupying 80 of the 160 original stations identified in the fixed grid created for this project (NA10NMF4540473). During the testing of gear modifications, it became clear that we could gain extensive knowledge by conducting seasonal surveys modeled after our gear projects. In 2011 we began the current seasonal bycatch survey primarily focusing on the relationship between seasonal fish distribution and seasonal variations in sea scallop meat yield. Gear design modifications to reduce bycatch remained a secondary focus (NA11NMF4540027). It requires multiple years of data to fully understand seasonal trends, therefore, the bycatch survey was repeated from May 2012 to March 2014.

During the 2012 project year we standardized the survey area and gear type. This improved our understanding of temporal and spatial patterns in fish bycatch and meat yield. We determined that bycatch rates were lowest in the spring months, with June 2012 having optimal low bycatch rates with high meat yield. Because we increased the biological sampling of the target species as well as bycatch species, we successfully identified semi-annual spawning of scallops on Georges Bank, gained insight on the timing of fish spawning and collected additional data for potentially important fish and scallop diseases on Georges Bank. Our data have been valuable to management including our data being incorporated into Framework 24, which changed seasonal closures on Georges Bank to reduce bycatch (NA12NMF4540034).

For the 2013 project, presented in this report, eight trips were made to scallop access areas in Closed Area I (CAI) and Closed Area II (CAII) and in the open area of Georges Bank from April 2013 through March 2014. Ninety-one stations were surveyed consistently on every trip, including 34 stations sampled continuously during the entire survey from 2010 until 2014 (Appendix C). The additional stations extended the fixed grid to improve data on seasonal fish movements. The 2013 project compared our 4.57-meter-wide New Bedford style dredge with the 4.57-meter-wide standardized turtle dredge, which has been used on every survey trip since 2010. All tows were conducted following standardized procedures and catch from each gear type was processed identically.

The focus of this project was to define the season influences on bycatch rates including, sea scallop shell height/meat weight relationships and changes in fish catch on a finer spatial and temporal scale the goal of optimizing scallop yield. Sea scallop shell height and meat weight data were collected on all cruises during the course of this study to estimate spatio-temporal patterns in meat weight.

Sea scallop meat weight was highest in June 2013 in all areas and lowest between September and December. As in 2011 and 2012 we continued to observe scallop spawning in both spring (May-June) and fall (September-October) yet the isotope analysis did not identify any adult animals from spring spawns. Scallops with gray meats or discolored meats were observed mostly in the southeast corner of CAI as a result of muscle deterioration likely associated with a newly-identified apicomplexan parasite. Scallops were also collected primarily from CAI with *Mycobacterium placopecteni spp. nov* infections causing visible orange nodules in the abductor muscle as well as other tissues (Grimm et al. *In review*). More data are needed on these identified diseases to make inferences to the overall effect on the stock.

The two dredges fished evenly in regards to total scallop catch while the turtle deflector dredge with a shorter apron caught significantly fewer windowpane flounder. Yellowtail and winter flounder catch was also lower in the turtle dredge but the difference was not significant. Yellowtail and windowpane flounder catches were highest in CAII, whereas winter flounder catches were highest in CAI. Consistent with observed bycatch rates, yellowtail flounder swept area biomass estimates were higher in CAII and the open area than in CAI. Biomass estimates were highest at 3460 metric tons (catchability q=0.248) from September-October 2013, with another peak in January 2013.

Yellowtail flounder reproductive staging indicated that peak spawning occurred in May-June 2013. Our data showed the winter flounder were ripe in March, yet no ripe and running females were identified during the survey, suggesting spawning may occur outside the study area. The disease sampling of yellowtail flounder showed that 70% had various parasitic nodules with 1.9% of yellowtail flounder having confirmed cases of *Ichthyophonus spp.* infection, which has been known to cause die-off events in other fish species.

During this project year we collected biological data on lobsters as well as gear related damage. While the catchability of lobsters is unknown for this type of gear, out of the retained lobsters we observed 32% of the lobster catch sustained lethal damage. It is expected that a high percentage escape the gear at the bottom. Our data is able to show lobsters, including berried females, moving into the survey area between July and November when the bottom temperature was warmer and leaving as the waters cool in December.

The data collected during the seasonal bycatch survey has proved very valuable to management. We addressed the primary goal of the project. Maximum meat yield coupled with minimum fish bycatch occurred in June in the survey area, demonstrating that this seasonal survey can help to optimize rotational management on Georges Bank. A seasonal bycatch survey of the northern section of Georges Bank will be conducted in 2015 to understand seasonal trends in this area. The 2015 survey will collect missing data on the northern portion of Georges Bank including the groundfish area closures currently under management review to be opened to the scallop industry after a long area closure.

Table of Contents

List of Figures

List of Tables

Introduction

The sea scallop, *Placopecten magellanicus*, is one of the most lucrative marine species in the northeastern United States and supports the most valuable wild scallop fishery in the world (Hart and Chute, 2004). The stock has been rebuilt and no overfishing is occurring. However, the scallop fishery is allocated a bycatch cap of yellowtail flounder (*Limanda ferruginea*) and if it is exceeded scallop harvest will be restricted. Furthermore, it is possible that if yellowtail stocks remain at low levels, the scallop fishery could be directly limited to further reduce bycatch. Management measures to constrain the harvest of sea scallops have resulted in the loss of millions of dollars to communities of the Northeast and Mid-Atlantic regions of the United States (O'Keefe and DeCelles, 2013).

Results from previous work during this survey were used to adjust seasonal closures to the scallop access areas on Georges Bank in Framework 14 (NEFMC, 2013). We continued the seasonal bycatch survey (NA11NMF4540027 and NA12NMF4540034) to extend the time series and determine whether seasonal patterns were consistent on an annual basis.

Seasonal data on scallop meat yield and groundfish bycatch rates were lacking prior to the seasonal bycatch survey. Spatial and temporal variation in scallop meat yield has been observed on Georges Bank in relation to depth, flow velocity, and water temperature (Sarro and Stokesbury, 2009). Also, variations in yellowtail bycatch rates have been noted in open and closed areas on Georges Bank through observer data (Bachman, 2009). However, using observer data for information pertaining to meat yield and bycatch provides no data in the absence of fishing, which includes seasonal closures on Georges Bank from February through mid-June. This survey fulfills the need to consistently monitor different regions of Georges Bank in order to gain a better understanding of seasonal variability in meat yield and bycatch rates.

The bycatch survey has been modified and adapted over the past three years to address new research areas. The primary goal of collecting seasonal information in order to optimize catch of the scallop fishery by seasonal variations in bycatch rates has remained the same in this project. Additionally we added biological sampling for studies examining scallop meat quality, disease, shell growth, and reproductive staging of scallops. We also sampled select flatfish species for reproductive maturity and disease assessment. During this project we began collecting biological data and scallop dredge-induced damage on lobsters. Two standardized dredge designs were also compared to test whether bycatch could be reduced via gear engineering.

General Sampling Methods

The project consisted of eight research trips aboard commercial scallop vessel simultaneously towing two standardized scallop dredges in a systematic fixed grid survey on Georges Bank focusing on scallop access areas in closed area I (CAI) and closed area II (CAII) as well as open fishing grounds on the southern edge of Georges Bank (open area: Figure 1). Each trip was approximately six days of sampling, with two days for steaming to and from the sampling grounds. Researchers determined that the data collected from adding additional stations to the 2012 survey grid for this funding year would collect more valuable data than increasing sampling frequency. The entire survey area was sampled every six weeks throughout the year. For this report the trips are labeled as the month in which the majority of sampling occurred. Ninety-one fixed stations were consistently sampled on each trip (31 CAI, 30 CAII, 30 in open area). CAI stations were spaced 5.39 km (2.9 nmi) apart longitudinally and 7.18 km (3.9 nmi) apart latitudinally (Figure 2). Stations in CAII and open area were spaced 8.55 km (4.6 nmi) apart longitudinally and 11.12 km (6.0 nmi) apart latitudinally (Figure 3).

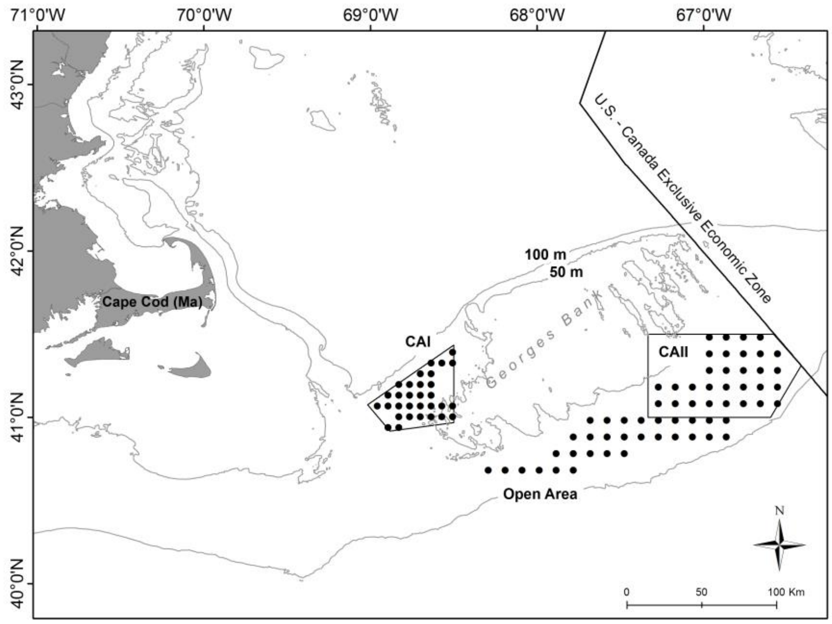


Figure 1. Locations of the 2013 CFF seasonal bycatch survey stations (black points) with stations categorized as CAI, CAII and open area. The open area stations are located outside of the scallop access areas.

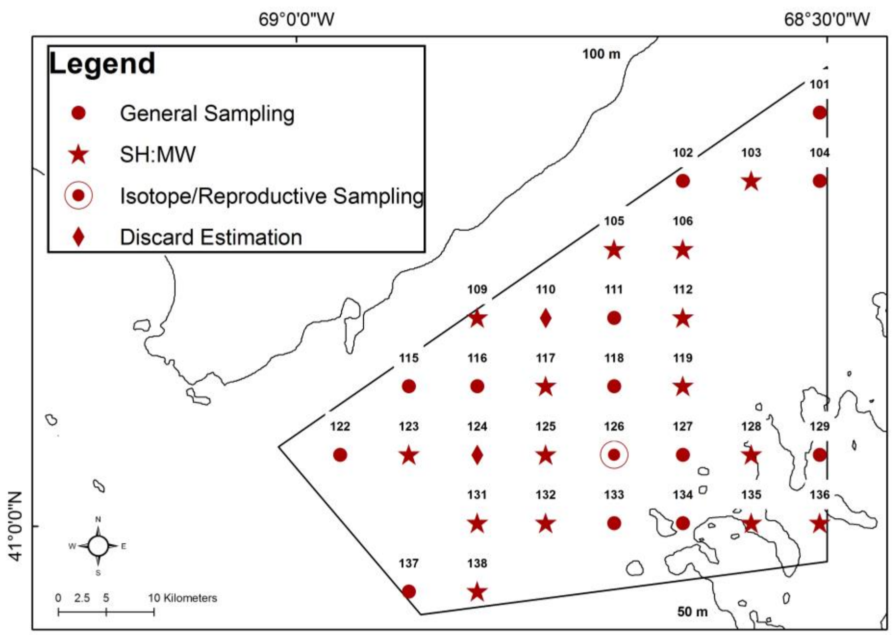


Figure 2. Map of 31 stations sampled in Closed Area I (CAI). Meat sampling (stars), scallop isotope/reproductive sampling (circled) and discard estimation stations are shown. Actual locations for special sampling stations were adjusted due to lack of scallop catch or priority of other sampling. Stations are 5.39 km (2.9nmi) apart longitudinally and 7.18 km (3.9 nmi) apart latitudinally.

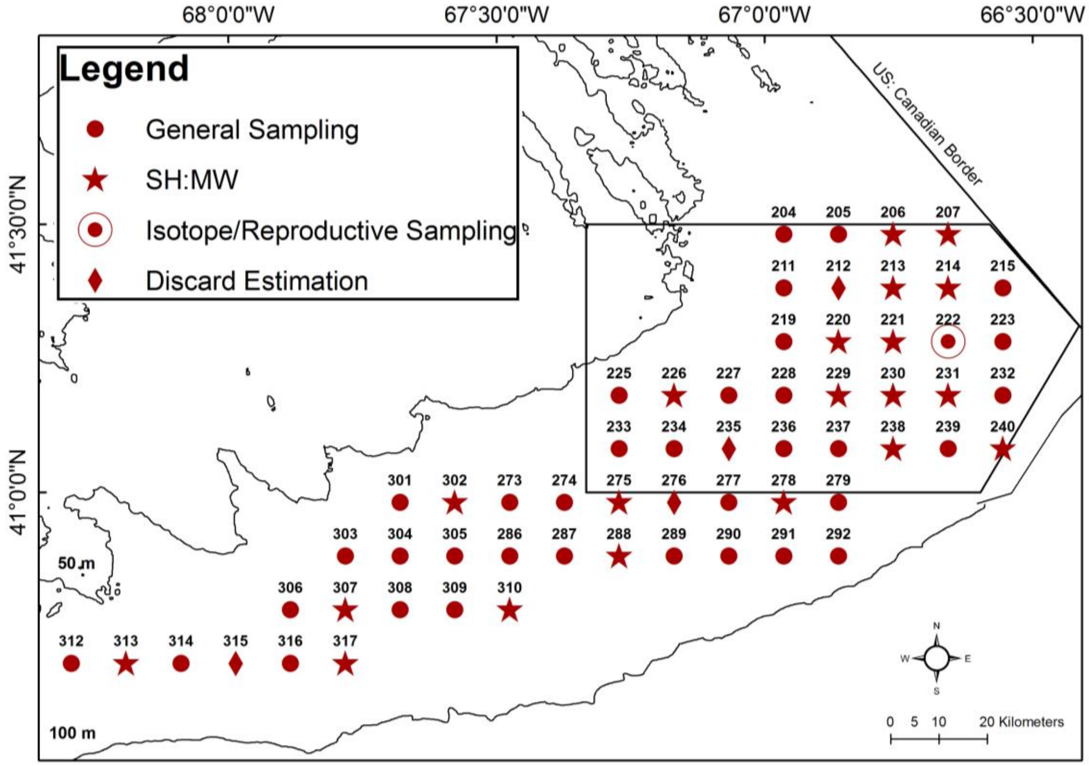


Figure 3. Map of 30 stations sampled in Closed Area II (CAII) and 30 stations sampled in open area. Meat sampling (stars) scallop isotope/reproductive sampling (circled) and discard estimation stations are shown. Actual locations for special sampling stations were due to lack of scallop catch or priority of other sampling. Stations are 8.55 km (4.6 nmi) apart longitudinally and 11.12 km (6.0 nmi) apart latitudinally.

The aim of this survey was to describe relative seasonal variation in bycatch rates, not to produce absolute abundance or biomass estimates. Therefore, station locations were selected based on a fixed, systematic sampling design, with the stations defined as single points. While it is easier to calculate survey variance with stratified random designs, systematic grids typically provide more precise estimates by minimizing the risk of missing concentrations and/or gradients typical in fish, and hence catch, densities (Hilborn and Walters, 1992; Blanchard et al., 2008).

In the 2013 Seasonal Bycatch Survey we continued efforts to reduce flatfish bycatch via gear modifications. All survey trips utilized one 4.57 meter (15 ft) wide Coonamessett Farm Turtle Deflector Dredge (TDD) and one 4.57 meter (15 ft) wide standardized New Bedford style dredge (NBD). In addition to the different headbale designs, the TDD had additional modifications compared to the NBD. The most noticeable difference between the dredges is that the NBD had a 10-row apron with a 3:1 mesh-to-ring ratio for the twine top while the TDD was rigged with an 8-row apron and a 2:1 twine top. These modifications were chosen using data from our gear testing project (NA12NMF4540041) to continue testing the effectiveness of a shorter apron length and reduced twine top hanging ratio at reducing fish catch. Each dredge had identical sweeps, 4-inch rings, and turtle chains. Full specifications are displayed in Table A-1.

At each fixed station the dredges were deployed simultaneously and towed at a target speed of 4.8 knots using 3:1 wire scope. Target duration was 30 minutes, with a minimum tow time of 20 minutes in the case of technical difficulties. Stations were resampled if the tow parameters were not followed or if there was a gear malfunction until an acceptable tow was completed. Tow direction was at discretion of the captain, who was instructed to pass through the station coordinates at some point during the tow. Tow start and end was determined by the captain when the winches were locked or engaged for haul back. All tow parameters were recorded, including average speed, start and end positions, depth, and sea conditions. A water temperature and depth logger (Star-Oddi milli-TD) was deployed in steel sheaths welded to the TDD to record depth and temperature every 30 seconds throughout the survey.

For each paired tow, the catch from each dredge was processed identically, with each catch separated by species and individually counted. The entire scallop catch was quantified as bushels (bu = 35.2 liters). A one-bushel subsample of scallops was selected at random from each dredge and measured in 5 mm shell height increments. Size frequency could then be derived for the entire catch by multiplying the number of scallops of each size class in the subsample by the total number of bushels. The commercially important finfish species and barndoor skates were measured to the nearest centimeter. Winter and little skates were counted together, but not measured, and categorized as “unclassified skates.” Table A-2 lists all species that were measured and/or counted by common and scientific name.

All lobsters caught were examined for damage caused by the tow (Smith and Howell, 1987) then measured and sex, presence of eggs, shell hardness and incidence shell disease was recorded. Composition and estimated quantity of benthos (including rocks, sand dollars, crabs, sea stars, clams and shell debris) was also noted.

At select stations, additional sampling was conducted according to objectives in later sections of this report.

Catch and Distribution

Catch was quantified by area (CAI, CAII, and open area) to identify seasonal and/or long-term patterns in scallop, flatfish (yellowtail, winter, windowpane, and summer), monkfish, and skate (barndoor and unclassified) catches. The total number of animals caught per tow was analyzed since tow duration and speed were standardized. However, there may have been slight variation in area swept. Total catch by species is displayed for each survey month in the following tables (1-3), and distribution of total catch was also mapped for each survey trip (Appendix B). For the entire time series of the seasonal bycatch survey (May 2011- March 2014), there were 11 stations in CAII and 23 stations in CAII which were consistently sampled on all trips allowing comparison in catch between years for the TDD, which remained constant for the survey (Appendix C). It was not possible to calculate confidence intervals for this dataset, since we used a fixed sampling design.

Table 1. Total catches in CAI by trip. Scallop catch is quantified in bushels and fish in number of fish. Abbreviations: scallops (SC), yellowtail (YT), winter flounder (WF), windowpane (WP), summer flounder (SF), monkfish (MF), barndoor skate (BD), unclassified skates (Skate).

Year	Month	SC	YT	WF	WP	SF	MF	BD	Skate
2013	May	71.4	39	26	279	3	17	5	5731
	Jun	53.4	89	106	96	69	233	14	5288
	Jul	60.4	58	231	361	58	312	127	7113
	Sep	62.6	88	149	600	82	251	84	8612
	Oct	56.1	34	134	613	12	229	109	6937
	Dec	58.2	49	161	443	0	53	45	7430
2014	Jan	49.8	12	19	541	0	8	17	6075
	Mar	50.3	9	7	183	0	0	0	1263
Total		462.2	378	833	3116	224	1103	401	48449

Table 2. Total catches in CAII by trip. Scallop catch is quantified in bushels and fish in number of fish. Abbreviations: scallops (SC), yellowtail (YT), winter flounder (WF), windowpane (WP), summer flounder (SF), monkfish (MF), barndoor skate (BD), unclassified skates (Skate).

Year	Month	SC	YT	WF	WP	SF	MF	BD	Skate
2013	May	227.9	178	8	661	6	95	56	5092
	Jun	199.4	124	6	82	1	200	124	2089
	Jul	233.7	305	10	56	4	237	127	4449
	Sep	206.8	649	31	31	21	244	108	4732
	Oct	203.3	472	23	159	33	237	63	3045
	Dec	166.5	169	13	390	16	101	32	2943
2014	Jan	157.9	269	15	1961	1	42	54	6425
	Mar	178.2	179	13	2100	1	1	4	8391
Total		1573.5	2345	119	5440	83	1157	568	37166

Table 3. Total catches in open area by trip. Scallop catch is quantified in bushels and fish in number of fish. Abbreviations: scallops (SC), yellowtail (YT), winter flounder (WF), windowpane (WP), summer flounder (SF), monkfish (MF), barndoor skate (BD), unclassified skates (Skate).

Year	Month	SC	YT	WF	WP	SF	MF	BD	Skate
2013	May	251.5	120	6	244	24	146	229	4843
	Jun	276.4	76	11	8	4	358	264	2102
	Jul	297.8	21	4	46	2	538	147	4039
	Sep	245.8	58	23	5	1	540	294	6214
	Oct	230.0	195	18	13	36	450	171	3378
	Dec	184.4	93	16	490	77	309	193	3731
2014	Jan	229.8	213	12	1136	10	184	237	13462
	Mar	209.9	89	0	1352	1	5	52	15438
Total		1925.4	865	90	3294	155	2530	1587	53207

For the 2013 survey scallop catch was highest in open area, intermediate in CAII, and lowest in CAI with no distinguishable seasonal distribution patterns (Table 1-3; Figures B-1 & B-2). Scallop catch in the closed areas was considerably lower in 2013 than it was in previous years (Figures C-1 & C-2). Concentrated fishing effort in the closed areas, especially in CAI, in 2011 and 2012 likely explains the steady decline in scallop catch over the three-year time series. This also partially explains why catch was greater in open area south of CAII as compared with catch inside the closed areas.

Yellowtail flounder catch was low and distribution was fairly uniform in CAI with a minor peak in the deeper stations June-September (Table 1; Figure B-3). In open fishing ground, yellowtail catches were relatively consistent with an observed peak October-January along the southern edge of CAII (Table 3, Figure B-4). Yellowtail flounder catch was highest in CAII for September 2013, specifically in the northeastern part of CAII (Table 2, Figure B-4). This fall peak in yellowtail catch is consistent with past years, however the 2013 catch was lower than 2011 and 2012, while CAI catch remained similar between years (Figure C-3 & C-4). The fish distribution data combined with the reproductive maturity data collected on this survey will help to identify the timing of yellowtail and winter flounder spawning and define essential fish habitat. Yellowtail flounder were caught southwest of CAII in open area when they were ripe in May, and gonads were spent or resting when yellowtail catch was high in CAII.

Winter flounder catches were highest in CAI for all months except March with catches peaking in July, whereas levels remained low in CAII and open area (Tables 1-3). Winter flounder catches were concentrated along the northwestern edge of CAI from July-October with the concentration shifting to shallower water in the southeast for the winter (Figure B-5). No observed aggregations were noted in CAII or the open area (Figure B-6). This summer peak in CAI is consistent with 2011 patterns in winter flounder catch, whereas catch was highest in CAI in 2012 in November (Figure C-5). We postulate that winter flounder moved into deep water north of the Channel in the summer then returned to shallower water south or southeast of CAI to spawn in the winter. Detailed offshore spawning information is still lacking for winter flounder yet it is known that offshore spawning does occur (Bigelow and Schroeder, 1953).

Windowpane flounder were observed in CAI during each survey cruise with the lowest catches occurring in June and highest catches from July to January. Fish were often absent from the northwestern edge of CAI (Table 1, Figure B-7). Catch remained relatively low in CAII and the open area between the June and October trips, the trips in May and December observed moderate catches and in the winter months catches were large throughout the open fishing stations and CAII with many stations catching more than 100 individuals (Tables 2 and 3; Figure B-8). The fall peak in CAI and very high catches in CAII in January through March were consistent with patterns observed in 2011 and 2012 (Figures C-7 & C-8).

Summer flounder catch was minimal, never exceeding 100 individuals per area (Tables 1-3). Catch was greatest in CAI in September in the shallower water near the southeastern corner and in shallower waters in open area December 2013 (Figure B-9 & B-10). Timing of peak catches was consistent with past years for both closed areas (Figures C-9 & C-10).

Monkfish catch was greatest in all three areas June through October, however monkfish catch was much higher in the open area (Tables 1-3). The late summer maximum in monkfish is consistent with the timing of peak catches in past years (Figure C-11 & C-12). Monkfish were common on the northern border of CAI in June and August 2012, were widely distributed from May through September 2012 in CAII and open fishing ground, and then were caught mostly in open bottom south of CAII July through December (Figure B-11 & B-12).

Barndoor skate catch reached maxima in the open area in June and September 2013 and was much lower in the closed areas (Tables 1-3). Catches in the open area were generally highest from August through November in CAI and slightly earlier in CAII from June through September for all three years of the survey (Figures C-13 & C-14). Barndoor skates were seen mostly south of CAII and on the northern edge of CAI (Figures B-13 & B-14).

Unclassified skates were by far the most plentiful bycatch species with roughly 1,200-15,000 individuals caught per area for each month (Tables 1-3). Skate catch was highly variable as in past years (Figures C-15 & C-16). The highest skate catches was in open area in March 2014 with high catches throughout the sampling locations (Figures B-15 & B-16)

Catch patterns in 2013 were generally consistent with 2011 and 2012 fish catches (Appendix C). Yellowtail flounder catch was highest on CAII in September 2013, which is consistent with the fall peak in past years. Flatfish and monkfish catch followed a very similar pattern to the 2011 survey, whereas there was more interannual variation in skate bycatch for both barndoor and unclassified skates.

Cod, haddock, dogfish and torpedo rays were also noted during this survey but not caught in substantial numbers.

Bycatch Rates

Length-weight conversions (Wigley et al., 2003) were used to estimate the total weight of each fish caught during each survey tow. Fish weight was calculated by 3 cm length increments and scallop meat weight was calculated by 5 mm shell height increments using the data collected from the shell height meat weight relationship. Bycatch rate was calculated for each trip by dividing the weight of fish bycatch (lbs) by meat weight of the scallop catch (lbs). Rates were plotted by area and dredge type, so as to allow general gear comparison. A low ratio is ideal for the fishery since it represents low fish bycatch in relation to scallop meat yield. Bycatch rates can sometimes be misleading since it does show relative catch between the target species and the discarded species. Locations which low target catch may have higher bycatch rates even with low numbers of discarded species.

Bycatch rates followed similar trends as fish catches, but represent the weight of bycatch species in relation to scallop weight (lbs fish/lbs scallops). Only TDD bycatch rates are presented here. Yellowtail bycatch rates peaked at 0.6 in September 2013 in CAII (Figure 4). Windowpane bycatch rates peaked at 1.06 and 1.02 in January 2014 in CAI and CAII, respectively (Figure 5). The bycatch rate of winter flounder was highest in July and December 2013 in CAI with a bimodal pattern similar to that of winter flounder catch (Figure 6). Summer flounder bycatch was low, but bycatch rate was highest in September 2013 in CAI (Figure 7). Monkfish bycatch rate was extremely high (3.13-4.41) from June through October 2013 in CAI (Figure 8). Monkfish are often landed by the scallop industry so their catch is not usually considered bycatch. Barndoor skate bycatch rate was high (3.57) in CAI in October 2013 (Figure 9). Only count data was collected for unclassified skates so bycatch rate could not be calculated for these species.

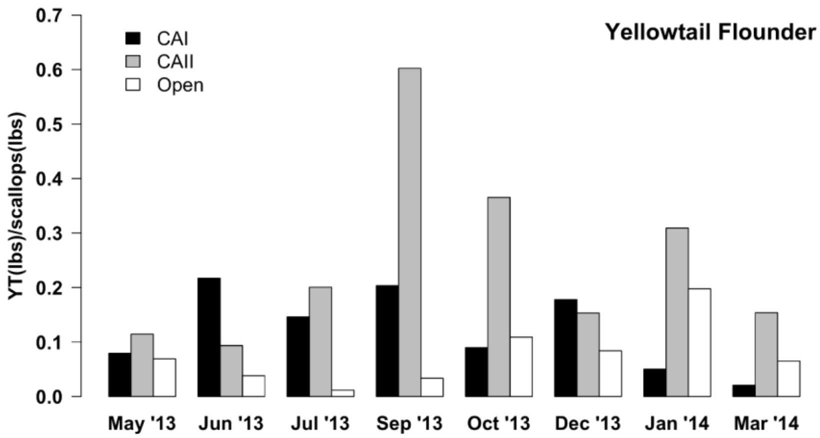


Figure 4. Yellowtail flounder bycatch rates (lbs of whole fish/lbs of scallop meats) for the TDD in CAI, CAII, and open area from May 2013 to March 2014.

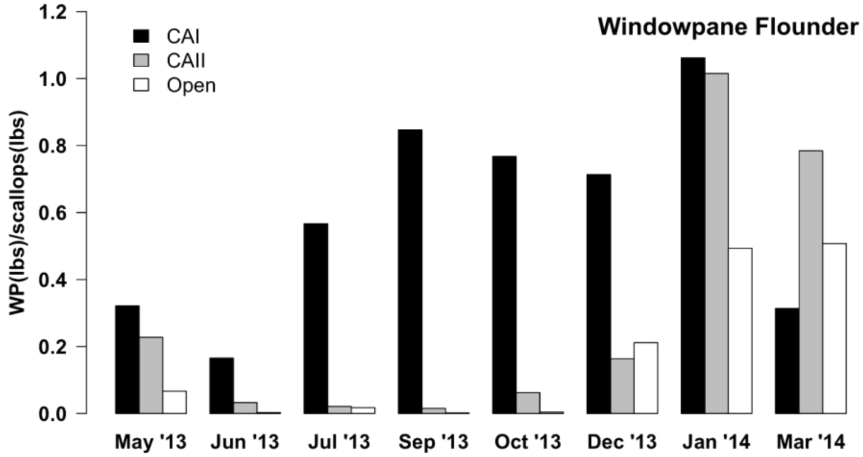


Figure 5. Windowpane flounder bycatch rates (lbs of whole fish/lbs of scallop meats) for the TDD in CAI, CAII, and open area from May 2013 to March 2014.

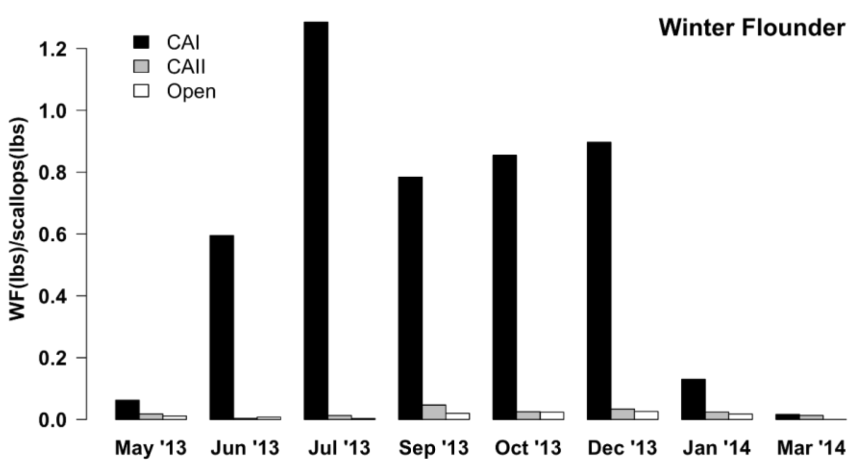


Figure 6. Winter flounder bycatch rates (lbs of whole fish/lbs of scallop meats) for the TDD in CAI, CAII, and open area from May 2013 to March 2014.

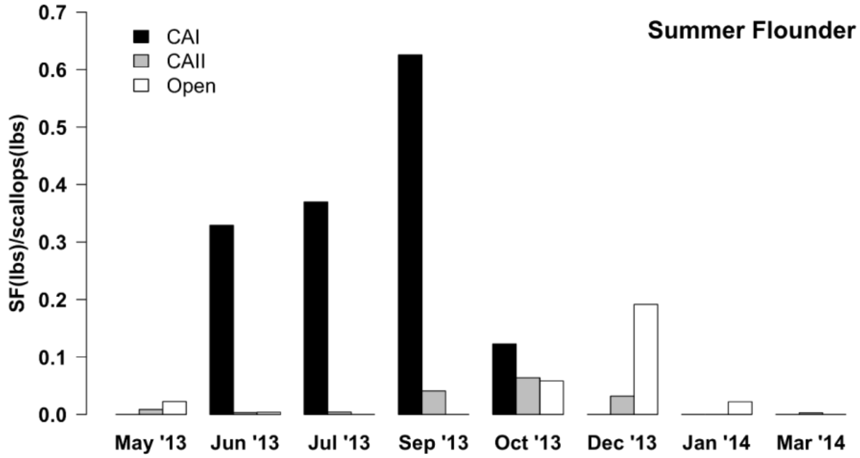


Figure 7. Summer flounder bycatch rates (lbs of whole fish/lbs of scallop meats) for the TDD in CAI, CAII, and open area from May 2013 to March 2014.

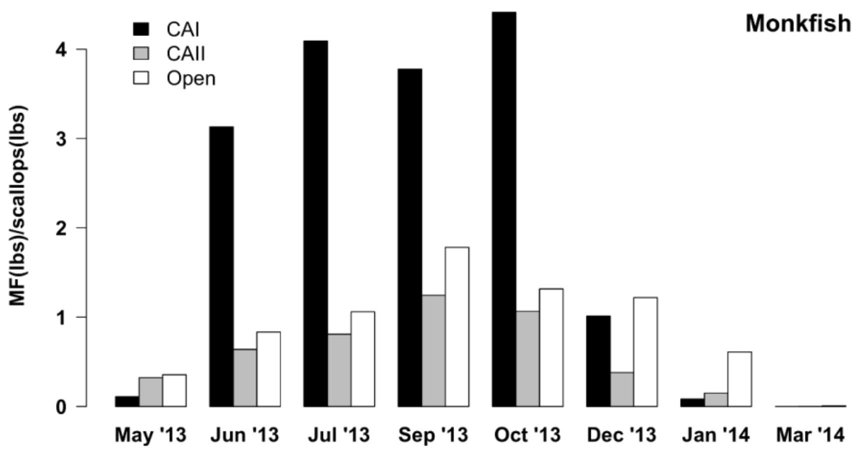


Figure 8. Monkfish bycatch rates (lbs of whole fish/lbs of scallop meats) for the TDD in CAI, CAII, and open area from May 2013 to March 2014.

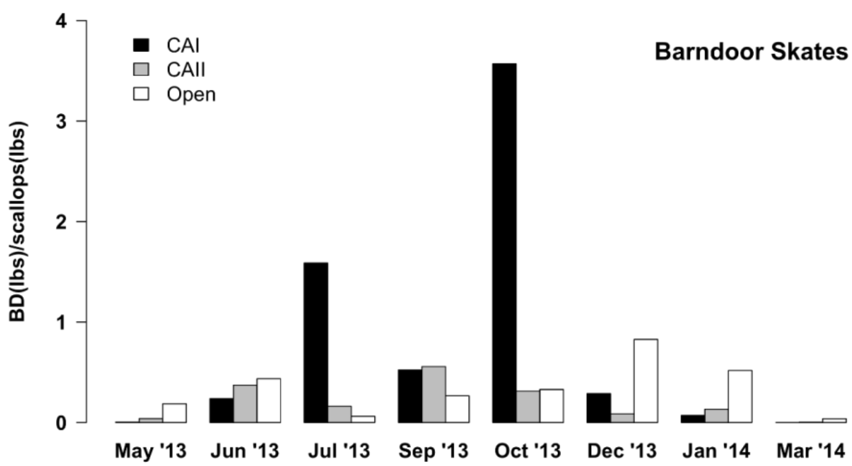


Figure 9. Barndoor skate bycatch rates (lbs of whole skates/lbs of scallop meats) for the TDD in CAI, CAII, and open area from May 2013 to March 2014.

For most fish species bycatch rate was low in May and June 2013 as well as in March 2014, with the exception of winter flounder and monkfish in June 2013 in CAI. This is logical since there was generally low fish catch (Table 1-3), and meat yield was high (Figure 15) during these months. Therefore, efficiency of the scallop fishery may be optimized in the spring months, and especially in May through June.

Gear Comparisons

Statistical Models – GLMM

Catch data from the paired tows provided the information to estimate differences in the relative efficiency between the two gear combinations tested. This analysis is based on the analytical approach in Cadigan et al., 2006. Our analysis of the efficiency of the TDD relative to the NBD consisted of multiple levels of examination. Additional details about the derivation of the model can be found in Appendix D.

The model assumes that each gear combination has a unique catchability and differences in scallop or fish catch between paired dredges will be reflected in the ratio of the catchability of the TDD (q_{TDD}) to the catchability of the NBD (q_{NBD}). The probability that a scallop or fish is captured by the TDD is $p=\rho/(1+\rho)$, where $\rho = q_{TDD} / q_{NBD}$.

If binomial regression is used to compare tows, a common practice because fishing catch data is typically over dispersed, and spatial heterogeneity of animal densities is incorporated, the logit (log of the odds) function of the binomial probability p is:

$$\log\left(\frac{p}{1-p}\right) = \beta + \delta_i \qquad (1)$$

After additional terms are added to account for catchability at length (l) and sub-sampling of the catch, the full initial model using unpooled by length catch data becomes:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0,\sigma_j^2), i = 1..n, j = 0,1\ldots \qquad (2)$$

The Alkaike Information Criteria (AIC) was used to select the best model configuration (Akaike 1973). If AIC and factor significance indicated that length was not a significant factor in predicting relative efficiency, the data was pooled over length and the random intercept model was evaluated to assess relative differences in total catch (Equation 1).

We used SAS/STAT® PROC GLIMMIX v. 9.2 to fit the generalized linear mixed effects models. Because paired tow data is still often analyzed using paired t-tests and Wilcoxon signed-rank tests, we ran these tests on a subset of the catch data to compare the results to those of the mixed models and assess the value of using these quick tests to assess catch data while at sea.

Catch Data Results

The data was from the eight survey cruises were treated as a single data set for the purposes of this analysis. For all cruises and all tows the gear compared was consistent. The TDD had its characteristic headbale (lower profile with forward cutting bar; Smolowitz et al., 2012) and an 8-row apron with a 2:1 twine top-to-ring ratio, and the NBD had a 10-row apron with a 3:1 twine top ratio.

Overall, this data set consisted of 728 valid tow pairs of which all were examined in the analysis. Not all species were present in all tow pairs and for the species examined, individual tows with zero total catch for a given species were uninformative for gear comparison and excluded from the analysis.

Statistical Models Results
This analysis attempted to construct a model that would predict the relative efficiency of the TDD (experimental) relative to the NBD (control) tested in the experiment based on a variety of covariates (Equation 2). In many instances, especially with gear modifications that can possibly alter the relative size composition of the catch, using the unpooled catch data and exploring the length-based relative efficiency becomes informative. This analysis utilizing the unpooled catch data predicts the changes that the TDD had on the relative catch at length for the two gears. For many species, however, length was not a significant predictor of relative efficiency. In these cases, an overall change in the relative total catch was possible and tested via a model specification using the pooled catch data (Equation 1).

Model Results
For some species, there was simply not enough data to provide meaningful results from the model. Most cases involved a small number of tow pairs where there were non-zero observations and the model failed to converge in these cases. Table D-1 shows the best model fit as determined by AIC for the various species in the analysis. Parameter estimates associated with each model specification are shown in Tables 2-3 of Appendix D. A summary of the difference between each gear type with the results from the GLMM on pooled-by-length catch data as well as additional statistical tests are displayed in Table 4. Graphical representations of the observed catches (either pooled or unpooled depending upon best model fit) and predicted relative efficiencies derived from the model output are shown as figures in Appendix D.

Table 4. Summary of gear comparison of pooled by length data for each species, showing the mean catch per tow for each gear type, the p-value from different statistical tests, the GLMM coefficient estimate, and the average percent change in the catch for the TDD relative to the NBD. Significant parameters are shown in bold. The complete binomial regression model output for pooled by length catch data is presented in Table D-3.

Species	Mean NBD	Mean TDD	p-value Wilcoxon (signed-rank)	p-value paired t-test	p-value GLMM	GLMM coefficient estimate	Percent Change
Spiny Dogfish	0.194	0.283			0.203	0.227	25.50%
Unclassified Skates	95.000	95.69			0.064	0.025	2.50%
Barndoor Skate	**1.669**	**1.842**	**0.014**	**0.020**	**0.019**	**0.100**	10.50%
Atlantic Cod	0.030	0.010			0.157	-2.751	-93.60%
Haddock	0.143	0.114			0.077	-0.383	-31.80%
American Plaice	0.117	0.110			0.744	-0.054	-5.20%
Summer Flounder	0.302	0.332			0.36	0.090	9.40%
Fourspot Flounder	0.912	0.875			0.713	-0.023	-2.30%
Yellowtail Flounder	2.548	2.380	0.209	0.064	0.06	-0.067	-6.50%
Winter Flounder	0.747	0.684	0.067	0.168	0.152	-0.094	-9.00%
Windowpane	**8.419**	**7.859**	**0.029**	**0.006**	**0.023**	**-0.056**	-5.50%
Monkfish	3.273	3.306			0.677	0.013	1.30%
Sea Scallop	2.712	2.729	0.057	0.455	0.075	-0.021	-2.10%

For the length-based model, sea scallops and windowpane flounder were the only species where this model specification provided the best fit to the data. Length was not a significant predictor for differences between the relative efficiencies of the two dredges for all other species. Across species, there was no clear directionality in relative efficiency using the TDD configuration relative to the NBD as length increased. Figures 10 and 11 show the graphical results for sea scallops and windowpane flounder as a function of length. For scallops, the increase in relative efficiency for the NBD with respect to length was slight and likely insignificant over the length classes of 100-150mm. This length bin is where the majority of observed animals were present and the statistically significant positive slope was driven by an observed increase in NBD catch of small animals (20-60mm). For windowpane flounder, the reduction in relative efficiency with respect to size was slight especially when viewed in the context of the portion of the length distribution where most of the observed animals were present.

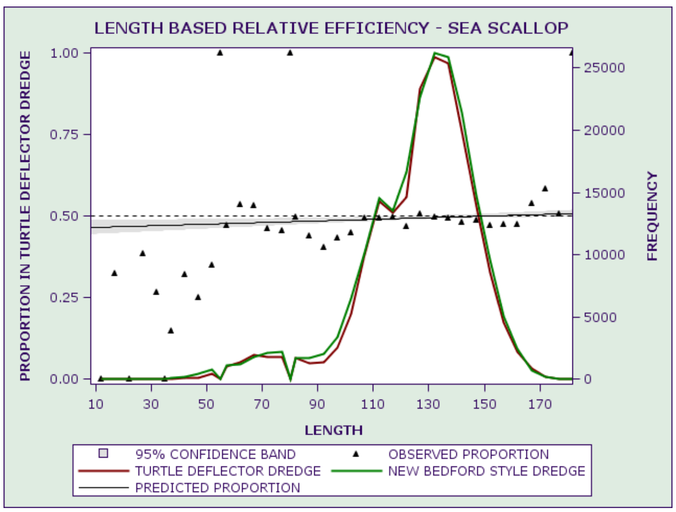


Figure 10. Relative sea scallop catch by the two dredge configurations, overlaid with size frequency for each dredge. The triangles represent the observed proportion at length ($Catch_{TDD}/(Catch_{TDD} + Catch_{NBD})$, with a proportion >0.5 representing more animals at length captured by the TDD dredge. The gray area represents the 95% confidence band for the modeled proportion (solid black line).

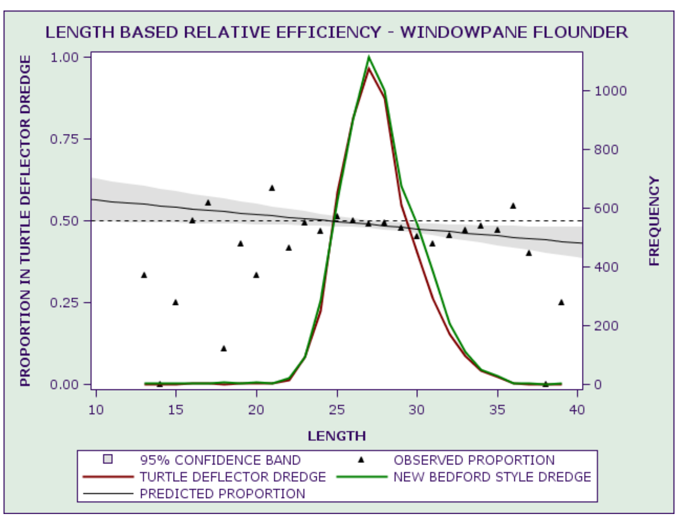


Figure 11. Relative windowpane flounder catch by the two dredge configurations,overlaid with size frequency for each dredge. The triangles represent the observed proportion at length ($Catch_{TDD}/(Catch_{TDD} + Catch_{NBD})$, with a proportion >0.5 representing more animals at length captured by the TDD. The gray area represents the 95% confidence band for the modeled proportion (solid black line).

Animal length was not a significant predictor of relative efficiency for many of the species analyzed and the catch data was pooled over length. When animal length was removed from the model, barndoor skate and windowpane flounder catches were significantly different between the TDD and NBD. For barndoor skates there was an increase in the relative efficiency of the TDD relative to the NBD, and the absolute estimated difference was roughly 10% (Table 4 & Figure 12). For windowpane flounder, there was a significant reduction in the relative efficiency of the TDD relative to the NBD of 5.5% (Table 4 & Figure 13). For the other species examined, there were no statistically significant differences in the overall catches between the two dredges. However, looking at signs of the coefficient estimates, there was an overall reduction of flatfish (winter flounder, yellowtail flounder, fourspot flounder, and American plaice) catch by the TDD relative to the NBD. These reductions, however, were generally small in the absolute scale (< 10%: Table 4). Care must be taken when interpreting the results from Atlantic cod and haddock. The data for these species consisted of a small number of tow pairs and the point estimates are highly uncertain with broad confidence intervals around them.

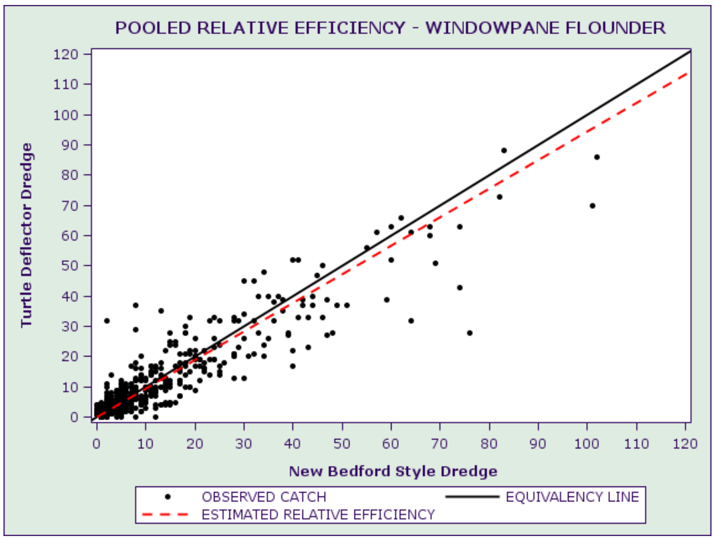


Figure 12. Total pooled catches for windowpane flounder for the TDD vs. the NBD. Model output indicated that the intercept only model was not the most appropriate specification. However, it is informative to see that the total catch of this species did differ between dredges in addition to a significantly different length relationship. Points below the black line represent higher catch in the NBD.

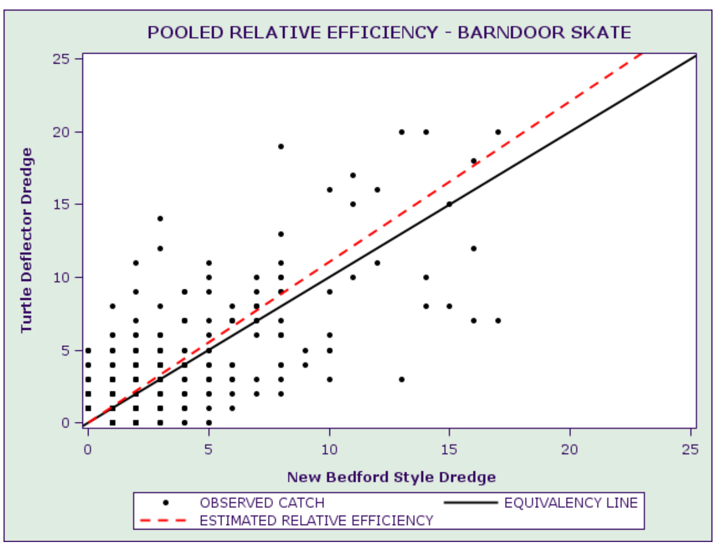


Figure 13. Total pooled catches for barndoor skate for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one. Points above the black line represent a higher catch in the TDD.

Our results indicate that in some cases, the modifications to the dredges resulted in differences in the catch of both the target species as well as the common bycatch species encountered during the survey. For windowpane flounder and scallops, the modeling showed significant differences in the length composition of the catches between the two dredges, while for other species, only the total numbers of animals differed. While the relative catches of other flatfish did not differ significantly between the two dredges, for all flatfish, except summer flounder, there was an observed reduction in catches of the TDD relative to the NBD. The model did not look at significant results on a trip-by-trip basis, but we did compare the two gear types for select species at this level using Wilcoxon signed-rank test (Table D-4). These results are informative because they provide insight into how dredge frame modifications affect individual species or similar groups of fish. With this insight, further modifications can be made in an attempt to facilitate additional reductions in bycatch. It is also important to verify the effect that dredge frame modifications have with respect to scallop catch as this is a significant factor in any gear modification.

Area Swept Biomass Estimation

The weight of each yellowtail flounder was calculated for each fish caught in the NBD using the measured length and seasonal length-weight relationship equation (Wigley et al., 2003) using the following equation:

$$\mathbf{\ln W = \ln a + b \ln L}$$

where W = weight (kg), L = length (cm), a = y-intercept, and b = slope.

No summer length-weight relationship for yellowtail flounder is available, so the weight-at-length of yellowtail flounder captured during survey trips in June and July were calculated using the average y-intercept and slope from the spring and autumn length-weight relationships (a = -12.0981 and b = 3.1329).

Area Swept Biomass Estimates

Yellowtail flounder catch rates and biomass estimates were compared between the three strata (CAI, CAII, and open area). For each survey trip, mean yellowtail flounder catch weights were calculated for each stratum. The stratified mean yellowtail flounder catch and the variance in catch weights of the entire sample (across all strata) was also calculated for each trip. A stratified random variance (Brust and Belcher, 2000) was used to approximate variance of the systematic design. The coefficient of variation in mean yellowtail flounder catch weights was also calculated for each survey trip (Sokal and Rohlf, 2001).

Estimates of yellowtail flounder density (kg/km^2) and area swept biomass (mt) were calculated by examining the observed catch of yellowtail flounder and the area swept by the NBD during each valid tow. The area swept by the NBD during each tow was calculated using the width of the dredge, the average speed of the vessel during the tow, and the tow duration.

$$\textbf{Area swept (km2)} = \textbf{dredge width (km)} * \textbf{tow speed} \left(\frac{\textbf{km}}{\textbf{hr}}\right) * \textbf{tow duration (hr)}$$

Tow speed was converted from knots to km/hr for area swept estimation. Tow duration was based on reported data from the captain. Bottom contact sensors were not used. The duration of each tow was converted from minutes to fraction of an hour for area swept calculations.
The density of yellowtail flounder observed during each survey tow was calculated as follows:

$$\textbf{yellowtail flounder density} \left(\frac{\textbf{kg}}{\textbf{km2}}\right) = \frac{\textbf{yellowtail flounder catch (kg)}}{\textbf{area swept (km2)}} * \left(\frac{\mathbf{1}}{\mathbf{q}}\right)$$

where q = 0.248 is the catchability coefficient that was estimated for the NBD during a comparative fishing experiment that was completed in September 2012 (see DeCelles et al., 2014 for details). Estimates of yellowtail flounder density and biomass are sensitive to the value of q that is used for the NBD. To address this sensitivity, density and biomass estimates were generated for each survey trip using a range of catchability coefficients that included the above estimate.

The area-swept biomass of yellowtail flounder was calculated in each of the three survey strata using the following formula, and the biomass estimates were converted from kilograms to metric tons to allow for comparison to the stock assessment.

$$\textbf{yellowtail flounder biomass (kg)} = \textbf{yellowtail flounder density (kg/km2)} * \textbf{survey area (km2)}$$

Each station in CAI represented an area of 38.74 km^2, while survey stations in CAII and the open area of Georges Bank represented an area of 94.82 km^2. During each survey trip, 31 stations were sampled in CAI and 30 stations were sampled in CAII and the open area combined. The total area sampled during each survey trip was 6890 km^2. The sampling footprint of the bycatch survey represented only 18.4% of the entire stock area for Georges Bank yellowtail flounder (37,334km^2, Larry Alade, *pers. comm*.).

The stratified mean yellowtail flounder catch rates varied substantially over the course of the year (Table 5). In general, the highest yellowtail flounder catch rates were observed in September and October, and moderate catch rates were observed during the winter survey trips in December and January. Catch rates were consistently lower in April, June and July. The variability in catch rates suggest that the availability of yellowtail flounder changes seasonally within our study area.

Table 5. The mean yellowtail flounder catch (kg/tow) across all three survey strata. The variance of yellowtail flounder catches across all strata is also provided, along with an estimate of the coefficient of variation for each trip.

Month	Stations Sampled	Mean Yellowtail Catch (kg/tow)	Variance	CV
May	91	1.07	0.012	0.011
June	91	0.82	0.020	0.024
July	91	1.08	0.049	0.045
Sep	91	2.58	0.134	0.052
Oct	91	2.48	0.247	0.100
Dec	91	1.14	0.017	0.015
Jan	91	1.57	0.075	0.049
Mar	91	0.76	0.018	0.023

Catch rates were quite variable between the three survey strata (Table A-3). In each month, the greatest catch rates of yellowtail flounder were observed in CAII. Peak yellowtail flounder catch rates in CAII were observed in September and October. A similar pattern has been observed on this survey in previous years, and above average yellowtail flounder bycatch rates have been reported to the SMAST Bycatch Avoidance Program in September and October. Observer data has also indicated high bycatch rates of yellowtail flounder occur in CAII in September and October (Scallop PDT, 2012). Catch rates in the open area were more variable, and there was no clear seasonal trend in yellowtail flounder abundance in the open area. Relatively low catch rates were observed in the open area in June, July and September, while the greatest catch rates were observed in January. Catch rates in CAI were lower than those observed in CAII on each survey trip. The greatest yellowtail flounder catches in CAI occurred in June, July, and September. The results strongly suggest that the productivity and abundance of yellowtail flounder varies throughout the Georges Bank stock area.

Area swept biomass estimates ranged from a maximum of 3462mt observed in September to a minimum of 1107mt that was observed in June (Table A-3 & Figure 14). Because the biomass estimates of yellowtail flounder are sensitive to the assumed catchability value that is used, area swept biomass was calculated for each survey trip and survey stratum using a range of catchability values (Table A-4).

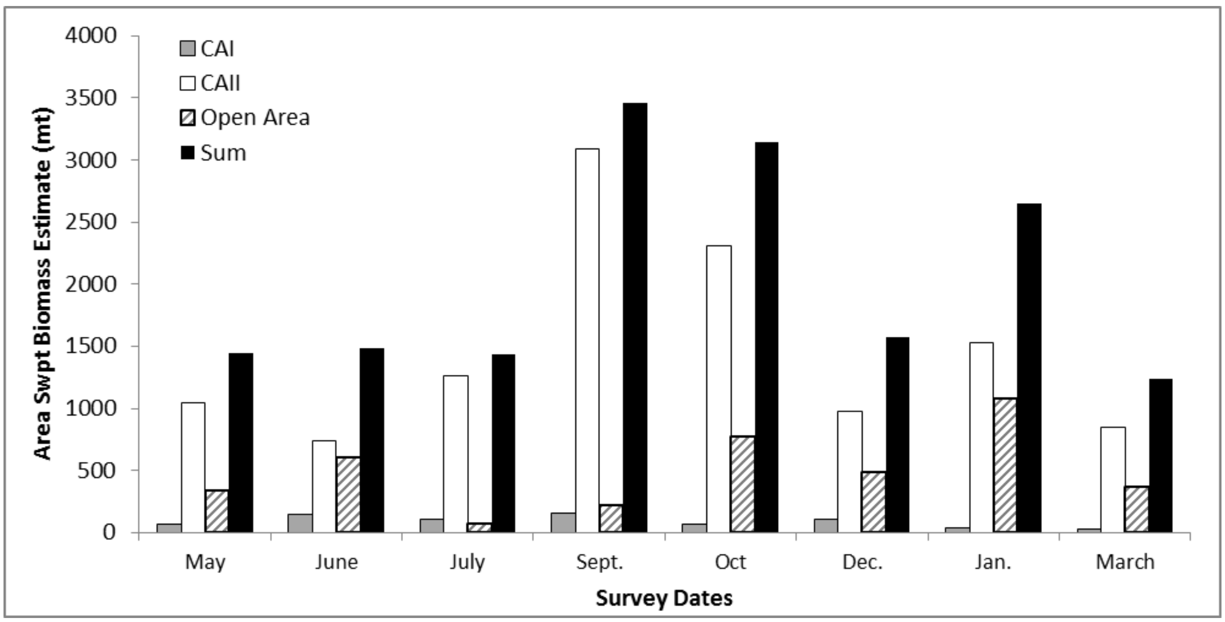


Figure 14. Estimated area swept biomass of yellowtail flounder observed in each survey strata during the eight survey trips that were completed between May 2013 and March 2014.

Changes in the seasonal distribution of the yellowtail flounder resource can have important implications for survey results and stock assessments and can also affect the bycatch rates of the scallop fishery on Georges Bank. Therefore, it is important to document changes in the seasonal distribution and catch of yellowtail flounder. This survey is unique in that yellowtail flounder were sampled throughout the year from Georges Bank. It offers valuable data that can be used to inform the design of resource surveys as well as assist in the development of new management measures. These biomass estimates were presented at the April 2014 Empirical Approach Stock Assessment meeting for Georges Bank yellowtail flounder (DeCelles et al., 2014).

Area swept biomass estimates from the seasonal dredge survey suggested that 2013 stock assessment underestimated the adult biomass of yellowtail flounder on Georges Bank. The area swept biomass estimates of yellowtail flounder derived from the eight survey trips were all greater than the estimate of adult biomass (826 mt) produced by the 2013 stock assessment (Legault et al., 2013). The biomass estimates from the bycatch survey are conservative, because we only sampled a small portion of the Georges Bank stock area, and the area swept method does not account for yellowtail flounder that were outside of the footprint of our survey.

Other sources of fisheries independent data such as industry-based trawl surveys and tagging experiments (e.g., Martin and Pult, 2014; Cadrin et al., 2014) were also considered during the April 2014 Empirical Approach Stock Assessment meeting. These independent data sources also suggested that the virtual population analysis (VPA) model used in the 2013 assessment underestimated the biomass of yellowtail flounder on Georges Bank. Rather than using the VPA model as the basis of catch advice, the 2014 TRAC used an absolute biomass estimate (2,213mt) derived from the NEFSC spring and fall trawl survey and the Canadian DFO trawl survey to form the basis of catch advice for 2015. The biomass estimate from the most recent stock assessment is more consistent with the results of the bycatch survey. However, biomass estimates from the bycatch survey in certain months does suggest that the updated stock assessment may still be underestimating the biomass of yellowtail flounder on Georges Bank.

Scallop shell height/meat weight relationship

Sea scallop shell height and meat weight data were collected on all cruises during the course of this study. The purpose of these collections was to estimate area and time specific relationships in an effort to document the annual variation in scallop meat weight. These estimates will provide a relative measure of scallop yield. Combined with estimates of the relative abundance of major bycatch species, this measure forms a baseline for optimizing harvest strategy.

Sample Collections

A subset of 35 stations (15 in CAI, 12 in CAII and 8 in the open area) within the study areas were randomly selected prior to the first survey cruise. These stations were sampled on the majority of cruises, with an exception of situations where no scallops were present or in rare instances where the samples were compromised prior to weighing. For these cases a secondary station was selected within that study area. At each of these stations 12 scallops comprising a representative range of observed shell sizes were selected for analysis. The top shell of each animal was measured to the nearest millimeter and the animal was then carefully shucked. The meat was blotted dry, placed in a pint zip-lock bag and then individually frozen. For each animal, station number, shell size, sex and reproductive stage were recorded. Upon return to port, each animal was weighed to the nearest 0.1 gram. In addition to the animal specific information recorded for each sample, associated tow specific information was linked to each sample. This information included depth, area designation and date of collection.

Analytical Approach

Sea scallop meat weight was predicted using a generalized linear mixed model (gamma distribution, log link). Scallop shell height, depth, sampling area (CAI, CAII, open area) and trip (characterized by month/year) were used as explanatory variables. The mixed modeling approach used a true likelihood based estimation that has multiple advantages. Traditionally, data of this type have been analyzed by least squares regression of the linearized data (i.e. lnMW*lnSH, NEFSC, 2010). One advantage of the mixed-modeling approach is the ability to define the underlying distribution of the data. The distribution that was used in this analysis was the gamma distribution that is generally considered a more appropriate distribution for data of this type (Hennen and Hart, 2012). This modeling approach also avoids the bias involved with back-transformations from log-linear models. In addition, random variation in the data can occur as a result of temporal and fine scale spatial variability in the process. Incorporating a random effect in the model accounts for this variability by evaluating the data at the station level and allows the intercept to be estimated for every time and station grouping. The station grouping variable consists of a unique code that included the year, month (temporal component) and station number (spatial component) from which the sample originated. This approach tends to capture and account for this variability more effectively relative to a model with only fixed effects and was evaluated by modelling the data with the same set of covariates that provide the best model fit without incorporating the random effect. A lack of improvement to this model relative to its mixed counterpart suggested that the variability introduced at the station level was an important attribute of the data. The Akaike Information Criteria (AIC) was used to select the best model configuration (Akaike 1973). Statistical analyses were completed using PROC GLIMMIX on the SAS system v. 9.2.

SH:MW Results

During 8 cruises from May 2013 through March 2014, a total of 3,841 scallops were sampled at 236 stations. Scallop shell heights ranged from 66 mm to 175 mm and meat weights varied from 5.2 g to 80.9 g. Spatial and temporal distributions of the collected shell heights and meat weights and log transformed shell height and meat weight data with various groupings (area, month) are shown in Appendix E.

Candidate models were evaluated and the model that produced the lowest AIC value was chosen as the model that best fit the data. Combinations of explanatory variables that were evaluated and resulting AIC values are shown in Appendix E. The selected model is shown below:

$$MW = e^{(\beta_0+\delta+\beta_1 * \ln(SH)+\beta_2*(D)+\beta_3*(M)+\beta_4*(L)+(\beta_5*(D)*L)+\epsilon)}$$

where δ is the random effect term (intercept), MW is scallop meat weight in grams, SH is shell height in millimeters, D is depth in meters, M is trip month when the sample was taken, and L is subarea (CAI, CAII and open area). An interaction term between depth and location is also included.

Based on an examination of residuals and QQ plot (Appendix E), model fit appears to be reasonable. There do appear to be a few outliers that consist of both heavier and lighter than expected meats. These observations could represent natural anomalies such as a diseased or senescent animal or simply an extraordinarily robust animal. While every effort was made to verify the quality of the data, some measurement error could exist in the data set. Regardless, the outliers were few and had minimal impact on parameter estimates.

Parameter estimates, shown in Appendix E, were reasonably precise and predicted increasing meat weight as a function of increased shell height and decreasing meat weight as a function of increasing depth. Meat weights were slightly higher in in the open area relative to the closed areas. The temporal trend indicated that meat weights were elevated through their peak from March-August and decreased to a trough from October – January. February and September were transition months. Temporal trends of a modeled 125 mm scallop for the three areas are shown in Figure 15. Estimated curves by month for the three areas are shown in Appendix E. Temporal trends for the three areas depicted relative to potential management measures for Eastern and Western Georges Bank are shown in Appendix E.

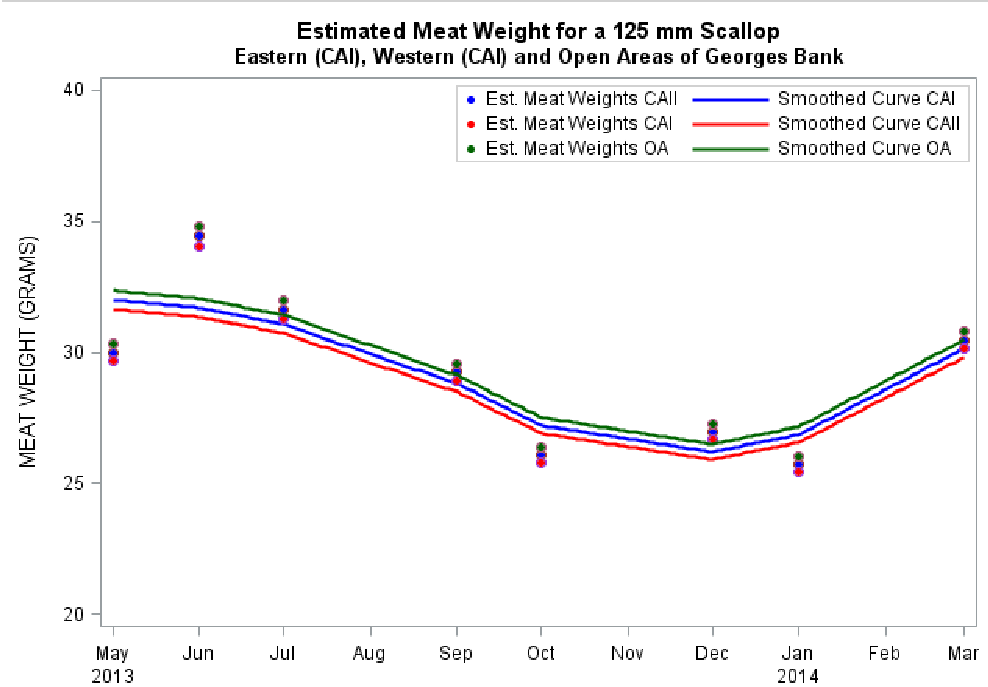


Figure 15. Temporal trends for the predicted meat weight of a 125-mm shell height scallop from the three areas. Estimated meat weights were calculated using parameter estimates from the model with the lowest AIC value (Appendix E).

Spatially and temporally explicit fishery-independent length weight information tends to be difficult to obtain on the scale that was collected by this study. These results document trends between the three areas on quasi-monthly basis and demonstrate that the differences between the areas that can be used in combination with the bycatch data included in this study to formulate a strategy to optimize the harvest of sea scallops in the Georges Bank Closed Areas.

Scallop Discards and Meat Loss

Meat loss due to undersized scallops and processing can result in a substantial loss of profit in the fishery if values used in management are inaccurate. Scallop discard rates are usually estimated from observers examining scallops remaining on deck after the crew picks the scallops to be shucked. This does not account for any meat loss during processing. Starting on the October 2013 bycatch trip, we conducted a pilot experiment in an effort to estimate discard mortality as well as the amount of meat lost from shucking and processing. Sources of meat loss include processing losses (e.g. meat tearing during shucking and washing) as well as losses due to poor meat quality.

During the December, January and March trips a total of 27 stations were randomly selected to estimate discard mortality as well as meat loss. To estimate discard mortality, scallops less than 115 mm in shell height were removed from one bushel and evaluated for shell damage or displaced hinges suggestive of lethal injury (Medcof and Bourne, 1964). The remaining scallops from the bushel were used to estimate meat loss resulting from the shucking process. The scallops were shucked by fishermen, who were instructed to separate shells, retained meats, viscera, and meats that would be discarded due to poor quality. The retained scallop meats were then washed and any separated “sweet” meats (smooth portion of adductor muscle) were weighed and classified as meat loss due to washing. Meat loss due to shucking was collected from the discarded material by scraping the shells and examining the viscera for torn meat fragments.

This preliminary data suggests that sources of meat loss are highly variable, which is expected with different bottom types, sea conditions, and seasonal changes in scallops resulting in changes of the quality. For this report, we combined data for all stations regardless of bottom type. Sample size was low, but our results indicated total meat loss of 19.8% with the majority being due to our classification of discards (Table 6). The cut off of discards at 115 mm is not representative of the scallop fleet, but instead determined using the 75% retention length of 4 inch rings (NMFS, 2007). We assume that some scallops smaller than 115 mm would be processed during fishing. Of the scallops that were classified as discards, 0.7-5.4% had lethal damage according to the standards of Medcof and Bourne (1964).

Table 6. Results from meat loss study showing percentage by weight of scallop adductor muscle retained vs meat loss during processing for trial experiment. This meat lost from discards was determined using shell heights under 115mm. The damaged discards were all scallops less than 115mm showing shell damage that had damage suggestive of mortality (Medcof and Bourne, 1964).

Month	Stations sampled (n)	Kept	Poor quality	shucking	Crushed	Washing	Discards	Damaged Discards
Oct	6	74.5%	1.7%	5.8%	Included in shucking loss	0.2%	17.8%	0.7%
Dec	6	82.5%	0.7%	5.7%	0.5%	0.1%	10.5%	1.7%
Jan	9	78.5%	3.8%	5.0%	1.4%	0.8%	10.4%	2.4%
Mar	6	86.0%	3.3%	5.4%	3.3%	0.5%	1.6%	5.4%
Total	27	80.2%	2.5%	5.4%	1.3%	0.4%	10.1%	2.5%

Gray Meat Study

In collaboration with the SMAST Scallop Research Set Aside (RSA) study “What Causes Gray Meat in the Atlantic Sea Scallop *Placopecten magellanicus* in Georges Bank Closed Areas?” (Inglis and Stokesbury, 2014; NA12NMF4540036), the meat color of samples collected for SH:MW analysis was recorded on five cruises from September 2013 until March 2014 using the color scale shown in (Figure 16). These data were used to map the occurrence of discolored (light brown, brown, and gray) scallops in the survey areas (CAI, CAII, open areas) and look at the shell height meat to meat weight relationship between white and discolored scallops, salmon colored scallops were excluded from this analysis.

Figure 16. Meat quality scale used to classify scallops during shell height meat weight protocol.

Discolored scallops were found throughout CAI with the greatest occurrence in the southeast portion, where over 50% of the scallop meats sampled were discolored (Figure 17). This finding was consistent with reports from fishermen. Discolored scallops were also found in high concentrations (25-49%) throughout CAII, although they were seen in lower concentrations than in CAI. Studies are currently being conducted to correlate environmental conditions with the location of these gray meat scallops ("Tracking the Occurrence of Gray Meat in Atlantic Sea Scallops, *Placopecten magellanicus*" NA14NMF4540080).

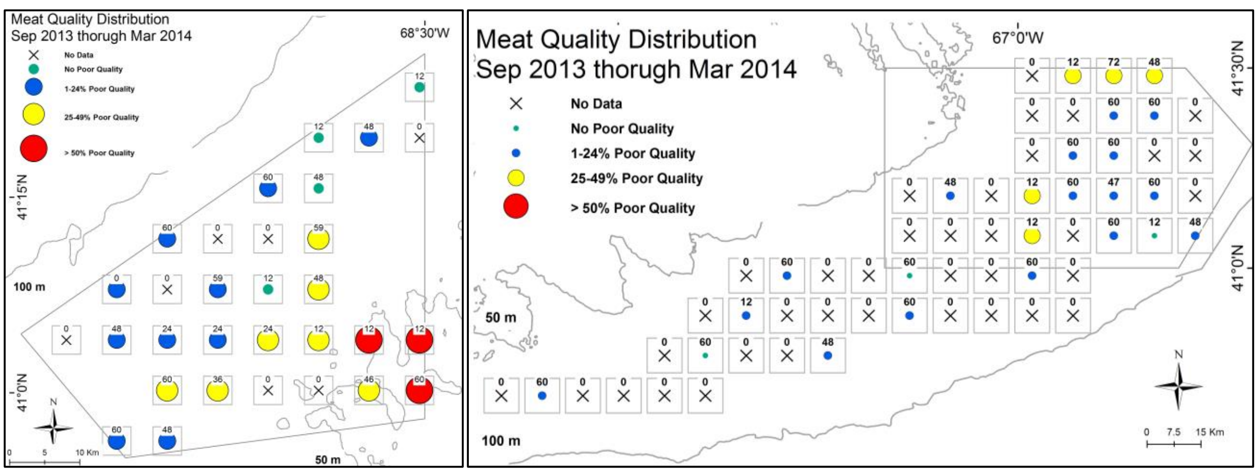


Figure 17. The percent of the shell height meat weight samples that contained discolored meat per station for CAI, CAII and open areas from Sept 2013-March 2014; red > 50%, yellow 25-49%, blue1-24%, green 0%. The number of scallops observed at each station are presented above each station.

Shell height (SH) and meat weight (MW) data from CAI and CAII were log transformed (Figure 18) and the data were tested for significance using an ANCOVA with MW as the dependent variable, color as the factor and SH as the covariate. There was a significant effect for SH and color (CAI SH: $F_{1,721} = 1571.6$, $p < 0.001$; CAI color: $F_{1,721} = 339.3$, $p < 0.001$; CAII SH: $F_{1,656} = 1526.2$, $p < 0.001$; CAII color: $F_{1,656} = 95.5$, $p < 0.001$), but not for the interaction term, for both CAI and CAII (complete results in Table A-12). A more parsimonious ANOVA model was used to test for differences in the slope without the interaction term. A significant effect of SH and color on MW was observed in both CAI and CAII (CAI SH: $F_{1,722} = 1573.5$, $p < 0.001$; CAI color: $F_{1,722} = 339.7$, $p < 0.001$; CAII SH: $F_{1,657} = 1521.3$, $p < 0.001$; CAII color: $F_{1,657} = 92.2$, $p < 0.001$) (complete results in Table A-13). Comparison of the ANCOVA and ANOVA models indicated that the more parsimonious ANOVA model was appropriate for both CAI and CAII (Table A-14). Linear regression was used to test for differences in intercepts. Gray meats were significantly smaller than white meats in both CAI and CAII (Table 7).

Table 7. Regression summary statistics for CAI and CAII.

CAI	Estimate	Std. Error	t value	Pr(>|t|)	
Gray					
(Intercept)	-4.3815	0.8419	-5.205	6.56E-06	***
SH	2.674	0.3978	6.722	5.17E-08	***
White					
(Intercept)	-3.90039	0.1339	-29.13	<2e-16	***
SH	2.55677	0.06353	40.24	<2e-16	***
CAII					
Gray					
(Intercept)	-5.8278	0.8484	-6.869	1.17E-08	***
SH	3.3891	0.3913	8.66	2.25E-11	***
White					
(Intercept)	-4.54568	0.15217	-29.87	<2e-16	***
SH	2.8523	0.07168	39.79	<2e-16	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Gray meat quality in scallops on Georges Bank has been linked to a newly identified genus and species of apicomplexan parasite that targets muscle tissue in the animal (Inglis and Stokesbury 2014). The parasite causes extensive muscle degeneration, reducing meat yield and quality as observed in this analysis. Scallops reported as "brown" in the survey were included in the gray meat category as they are an intermediate stage of the disease. The full report on gray meat in Atlantic Sea Scallops is presented in Inglis and Stokesbury, 2014; NA12NMF4540036.

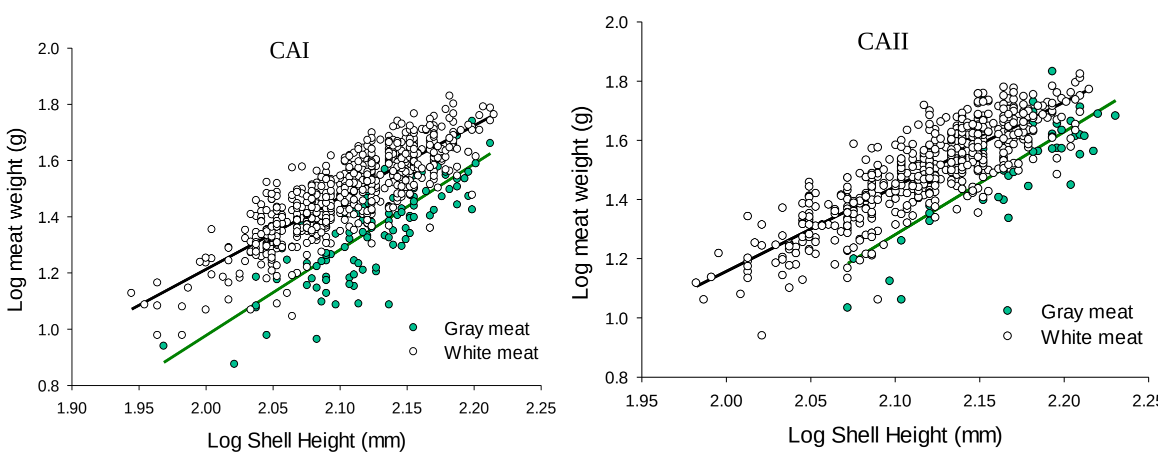


Figure 18: The log-transformed shell height meat weight relationship between gray and white meat scallops in CAI, n=663 (left) and CAII, n= 867 (right) from September 2013-March 2014. Samples from open area were not graphed. There was a significant reduction in meat yield (ANOVA p<0.001) in both areas.

Timing of Scallop Spawning

Sampling was also performed to identify the timing of sea scallop reproduction in the study area. Although Georges Bank supports the largest wild scallop fishery in the world (Caddy, 1989), little is known about spawning patterns in this region. Georges Bank scallops were considered fall spawners prior to this study, despite evidence of spring spawning in this area (DiBacco et al., 1995, Almeida et al., 1994). This study provided the first conclusive evidence that spring spawning consistently occurs in the Closed Areas on Georges Bank (Thompson et al., 2014).

Samples were collected on each cruise from March 2011 to June 2013 to examine seasonal effects on sea scallop reproduction on Georges Bank. Live scallops (n = 30-50) in good condition and approximately 130 mm in shell height were collected from stations 126 and 222 and were frozen whole. In the lab, gonads were oven-dried to constant weight at 80°C and the dry gonad weight was recorded. Gonosomatic index (GSI) was calculated (GSI = [Gonad Dry Weight/Total Tissue Dry Weight]*100; Barber and Blake, 2006). A Mann-Whitney test was used to identify statistical differences in mean GSI between months, since data were not normally distributed. Spawning events were identified by a significant difference in GSI between months where GSI decreased. Gonad tissue samples (n = 20: 10 females, 10 males) were collected at each station from June 2011 to November 2012 and preserved in formalin for histological analysis. Reproductive stage was verified microscopically.

Spawning was semiannual in both areas in 2011 and 2012 with a spring spawn observed in 2013 at the end of the data collection period (Figure 22, Thompson et al., 2014). GSI was significantly different between months (Mann-Whitney test, $p < 0.05$) where values were decreasing in both the spring (May to June) and the fall (September to October) of both years, indicating that spawning was semiannual (Figure 19). The magnitude of the fall spawning event was greater than spring spawning at the two stations in both years (Figure 19). Results from histological analysis confirmed spring and fall spawning events.

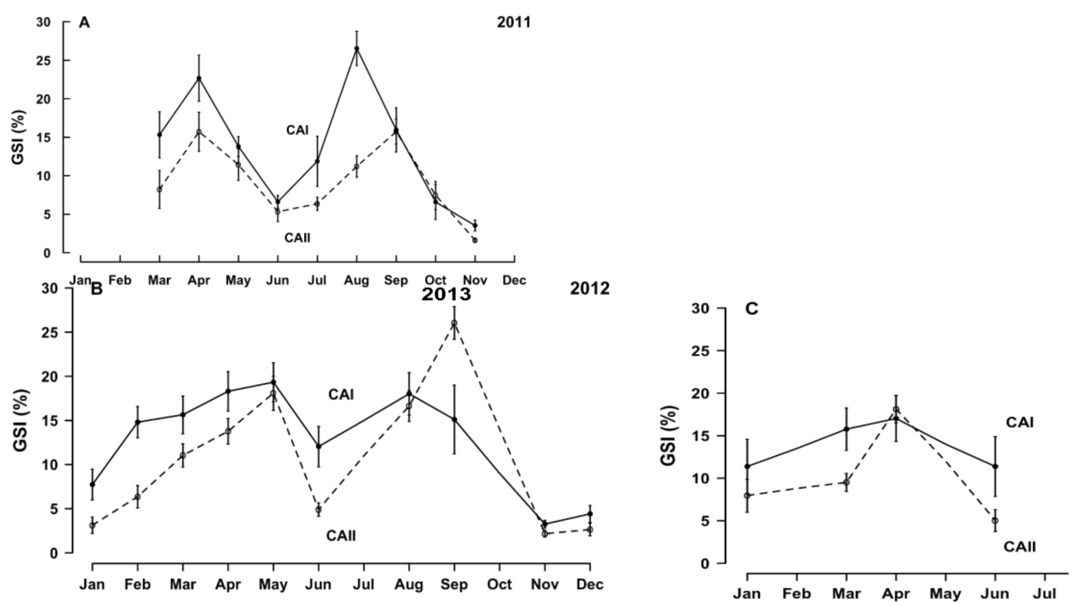


Figure 19. Mean dry gonosomatic index (GSI) samples collected from stations 126 and 222 March 2011 until June 2013.

Dry weight and histological analysis confirmed that spawning was semiannual in both areas in 2011 and 2012 and the spring spawn also observed in 2013 (Thompson et al., 2014). The spring peak in carbohydrate content observed in the proximate analysis of the scallop adductor may be a compositional modification associated with the semi-annual spawning as it coincides with changes in the GSI. We are awaiting results from energetic analysis conducted on gonad samples to confirm this energy transition. Our results confirm that glycogen is the major energy source for scallop adductor muscle tissue.

Different bottom temperature patterns at stations 126 and 222 represent differing physical oceanographic conditions and may explain the disparity in GSI between areas. Depth at stations 126 and 222 only differs by approximately 15 meters, but varying oceanographic dynamics could result in lower food availability at station 222 than at station 126. Lower food availability is a possible explanation for the observed differences in GSI between these locations.

Semiannual spawning has major implications for the stock assessment and management of the Georges Bank fishery. A biannual spawning pattern directly affects growth estimates and shell height/meat weight relationships, which would alter yield projections and fishery allocations. Further research needs to be conducted to understand the implications of semi-annual spawning on annual meat weight relationships and recruitment.

Isotope analysis:

Environmental influences on shell growth were evaluated by examining stable isotope deposition in scallop shells. Scallops have a sequential skeletal deposition, which provides a good medium for archiving environmental and physiological changes in growth. Oxygen isotopes are thermodynamically sensitive and the fractionation of $^{18}O/^{16}O$ ($\delta^{18}O$) is mediated by the reaction temperature (Tan et al., 1988; Krantz et al., 1984). Numerous studies have shown that the sequential $\delta^{18}O$ signature in bivalve shell carbonate fluctuates with water temperature (Goewert and Surge, 2008; Owen et al., 2002; Jones and Quitmyer, 1996; Tan et al., 1988; Krantz et al., 1984). In the summer, at warmer sea water temperatures, fewer of the heavier ^{18}O isotopes are incorporated into the shell carbonate resulting in a “lighter or depleted” isotope value. In the winter, the opposite is true and more of the heavier isotope is deposited in the shell producing a “heavier or enriched” isotope signature. Thus, the $\delta^{18}O$ signature in scallop shells can provide an estimate of seasonal growth and age (Jones and Quitmyer, 1996; Krantz et al., 1984). As the carbonate $\delta^{18}O$ signature reflects the water temperature when the shell was deposited, the $\delta^{18}O$ value from the umbo can indicate if a scallop originated from a spring or fall spawning event.

A subset of top shells from scallops with shell heights of approximately 100 mm from the stations 126 (CAI) and 222 (CAII: n = 20), collected from the 2012 bycatch survey, were used for this analysis. These shells were scrubbed clean of any exterior organic debris, rinsed with distilled water, and then air dried. The shell carbonate powder was collected using a Dremel® diamond head drill with a flexible arm attachment. The outer shell layer was micro-drilled every 0.5-1.0 mm along and parallel to the axis of maximum growth from umbo toward shell margin for 7-13 mm (Figure 20). A minimum of 100 micrograms were collected from each sample site on the shell. The carbonate powder was transferred to a micro centrifuge tube, and the samples were submitted to a laboratory for ^{18}O isotope analysis. The samples were analyzed using

Finnigan MAT 251 triple-collector gas source mass spectrometer coupled to a Finnigan Kiel automated preparation device. The isotope values were reported in the conventional delta δ notation as the enrichment or depletion of ^{18}O (parts per thousand ‰) relative to the Peedee belemnite (PDB) carbonate standard (Peterson and Fry, 1987). The predicted water temperatures during shell formation were determined using the paleotemperature equation by Epstein et al. (1953) and modified by Craig (1965):

$$\delta^{18}\mathrm{O}_{(\mathrm{calcite})} = \delta^{18}\mathrm{O}_{(\mathrm{water})} + \frac{4.2 - \sqrt{17.64 - 0.52(16.9 - T)}}{0.26}$$

where T = ambient temperature (°C).

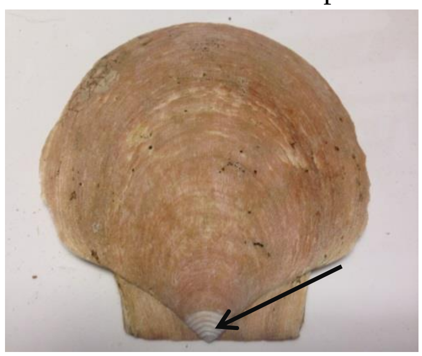


Figure 20: Carbonate sample sites for $\delta^{18}O$ analysis to determine if scallop developed from a spring or fall spawning event.

This value was correlated with the actual water temperature collected from two temperature loggers (Minilog V3.09, Vemco) deployed in steel sheaths and welded to each dredge to measure depth and water temperature at the time of sample collection. The predicted temperature from $\delta^{18}O$ was correlated with the actual temperature recorded at the sample station providing an estimated date of shell formation and thus whether the animal originated from a spring or fall spawning event. These data were also combined with Finite-Volume Coastal Ocean Model, FVCOM model (Chen et al., 2006) data to provide annual profiles of the bottom water temperature at these two stations over time.

The mean monthly water temperature collected from temperature loggers (Minilog V3.09, Vemco) for stations 126 and 222 are presented in Figure 21. The bottom temperature regimes between the two stations are significantly different (ANOVA, $p < 0.05$; Zar 2010) suggesting differences in ocean stratification in the area. Station 126 describes a mixed stratification with scallops experiencing seasonal differences in water temperature (7.0 - 17.6° C). Station 222 is a more stratified area as indicated in the overall lower annual temperature (6.2 – 11.9° C). Station depths and average bottom temperature by trip are reported in Tables A5-A7.

The predicted water temperatures calculated from the $\delta^{18}O$ for each carbonate sample are presented in Figure 22. The results from station 126 show a temperature range of 11.5-15 ^{0}C, increasing from the umbo to the shell edge. Based on the temperature data in Figure 21, this temperature range and trend describes spring water temperatures in this area. In the station 222 samples, the predicted water temperatures ranged from 6.5-10 ^{0}C, again with an increasing trend towards the shell edge and indicating spring water temperatures.

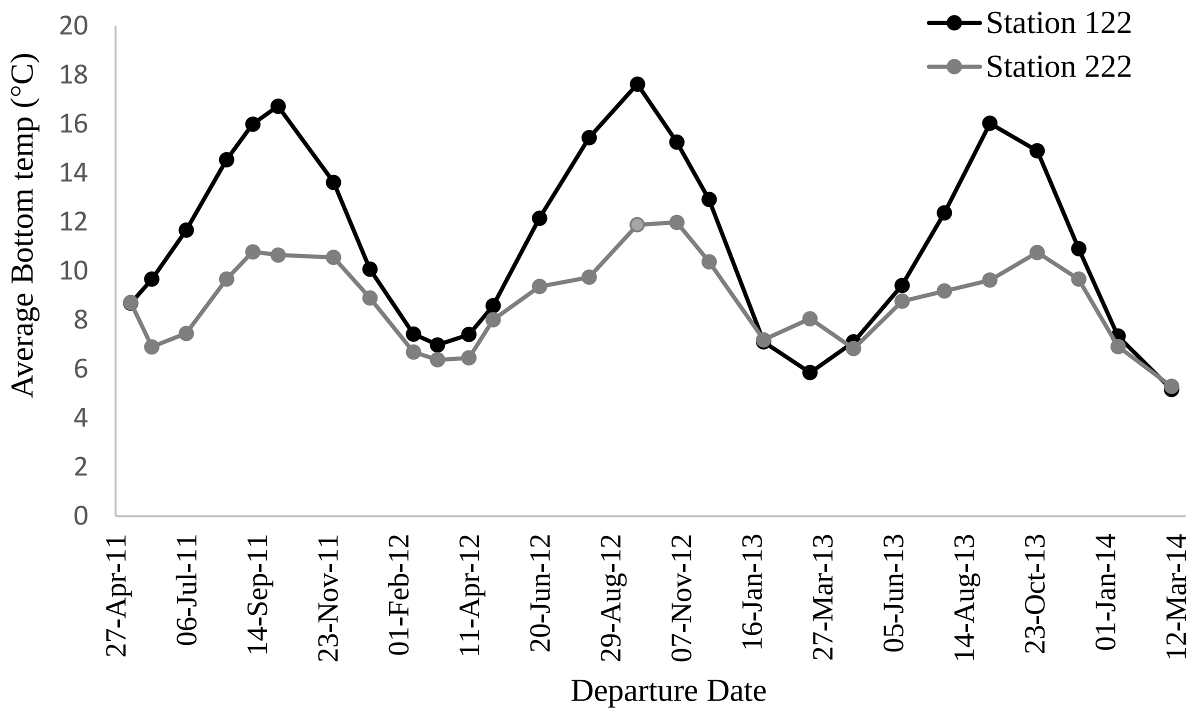


Figure 21: Measured mean bottom temperature for stations 126 and 222 for the duration of the seasonal bycatch survey. Water temperature data from April 2011-June 2013 was used for the isotope back calculation study

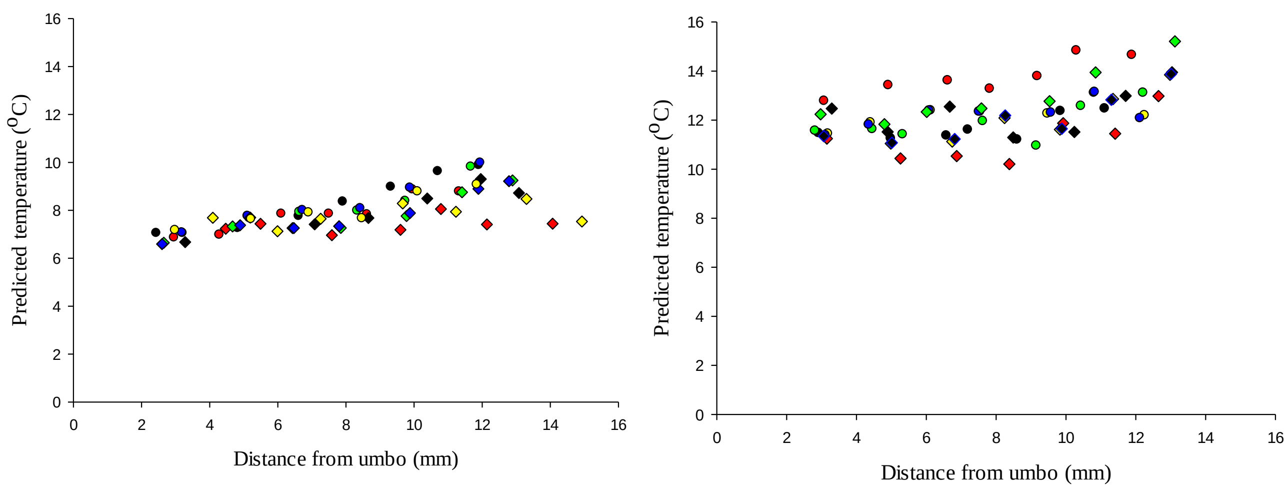


Figure 22. The predicted water temperature during shell formation based on the $\delta^{18}O$ shell carbonate values. Sample from 222 (n=10) are on the right and 126 (n=10) on the left.

Based on the initial carbonate sample at ~2-3 mm, the scallops appear to be about 5-6 months old (Stewart and Arnold, 1994). Based on the duration of the larval stage and early growth rate (Chute et al., 2012; Milke et al., 2004), the isotopic patterns in both the CAI and CAII samples are consistent with fall-spawned scallops. The ^{18}O isotope analysis from this study did not find evidence of spring spawning in the animals sampled, but the sample size tested was small (n=20). However, our results confirm that isotope analysis can be used to back calculate to time of spawning (Chute et al., 2012), and with an increased sampling regime may provide insight into the contribution of spring spawned scallops on Georges Bank.

Orange Nodules

Scallops with visibly identifiable orange nodules (Figure 23) in any tissue were opportunistically collected on each research trip. If sea scallops were observed to contain orange nodules, nodules and surrounding tissue were removed and processed for pathogen identification. The number of scallops examined was not always recorded due to priority of other research. All scallops containing orange nodules were photographed, measured, and tissues containing the orange nodules were excised and preserved.

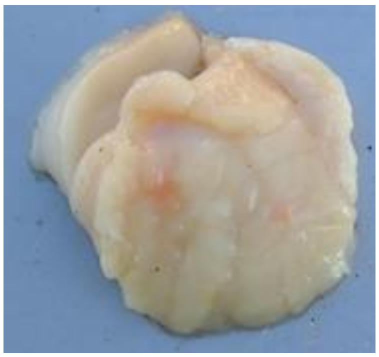
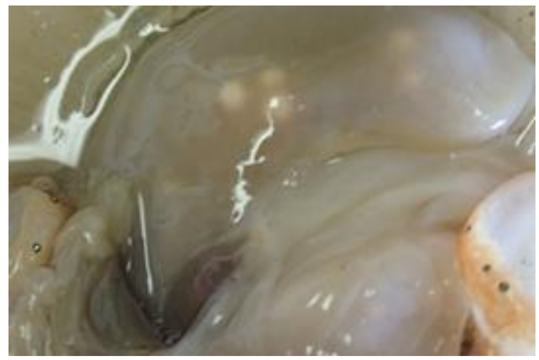


Figure 23. Examples of scallops with observable orange nodules in the abductor muscle (Left) and gonad (Right)



Tissues containing nodules were preserved in 10% formalin in sea water then tissue were embedded in paraffin, sectioned (6µm), and stained with hematoxylin and eosin (n=29). Selected samples were also stained with acid fast and tissue gram stains using standard methods (Mass Histology Service, Worcester, MA). Stained sections were evaluated histopathologically for appearance of lesions and location in the tissue.

Genetic studies were conducted on 25 of the samples by excising tissue with the orange nodule, preserving it in 95% ethanol then extracting DNA in the Aquatic Diagnostic Laboratory at Roger Williams University using Qiagen DNEasy Blood and Tissue Kit, according to manufacturer's protocol (Cat#69504). Amplification of the 924-bp fragment of the 16S gene was performed with primers T_{39} and $T_{13.}$ Single-strand sequencing was completed for DNA extracted from five animals at the University of Rhode Island sequencing center.

Scallops with identifiable orange nodules were identified during every survey cruise for this project with the majority of samples located in CAI (94%). Histological examination indicated that orange nodules were caused by infection with an acid-fast positive rod-shaped bacteria. PCR performed on the hsp667 gene identified the causative organism of the orange nodules as having > 97% genetic similarity to *Mycobacterium spp.* The orange coloration at the infection site is caused by the scallop inflammatory response, not a specific response to *Mycobacterium.* Therefore the presence of *Mycobacterium* in scallops cannot be determined only based upon the presence of orange nodules. A publication identifying the causative agent for the orange nodules in sea scallops as *Mycobacterium placopecteni spp.* nov has been submitted to the J*ournal of Disease in Aquatic Organisms* (Grimm *et al., in review*).

Yellowtail and Winter Flounder Maturity

Maturity data was collected for yellowtail and winter flounder on all valid tows on each research trip from May 2012 through March 2013. All fish (if less than 10 fish) or a sub-sample of 10 fish per species were sampled using the NEFSC 6-stage maturity criteria (Burnett et al., 1989).

Yellowtail Flounder

In total, 2,709 yellowtail flounder were measured and staged for maturity with 2,224 females and 485 males. The mean size of all females sampled was 38.39 cm, while 34.35 cm was the mean size for male yellowtail flounder. The relative percentages of yellowtail in each stage are characteristic of the status of egg development in the population. The maturity stages of yellowtail indicated there was a spawning event in the spring from May through June, followed by yellowtail flounder resting until September/ November when they began to develop for the next spawning season (Figure 24 & 25 Table A-8).

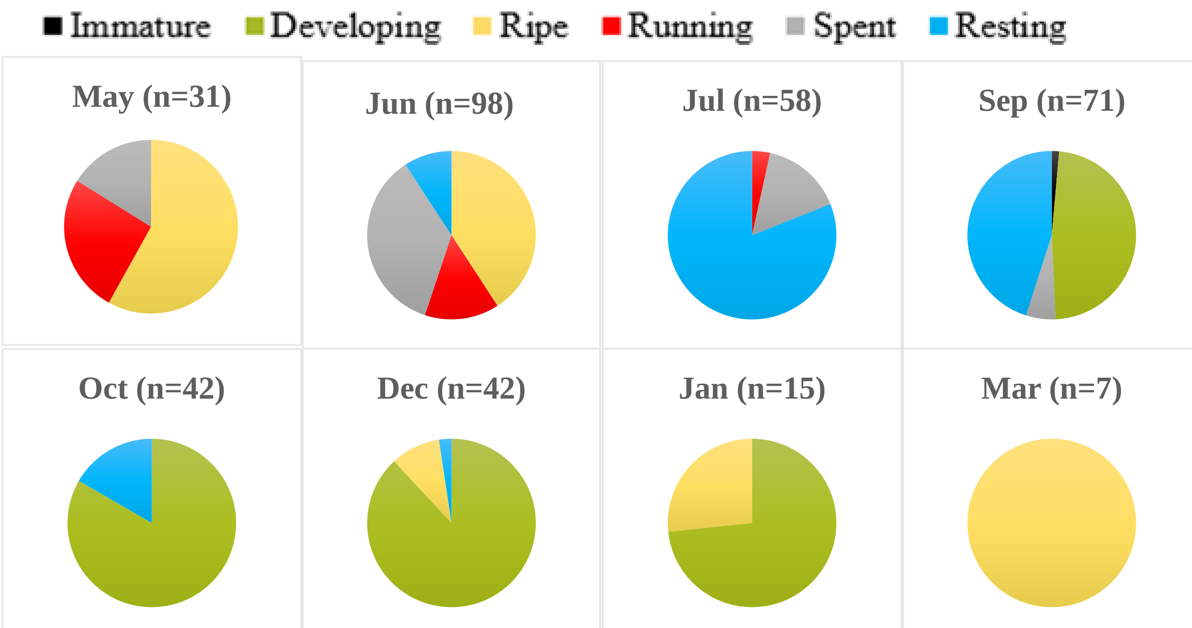


Figure 24 Seasonal maturity results of female yellowtail flounder in CAI for each month of the survey, highlighting the relative percentages of each stage. With the number of fish examined recorded in the legend for each month.

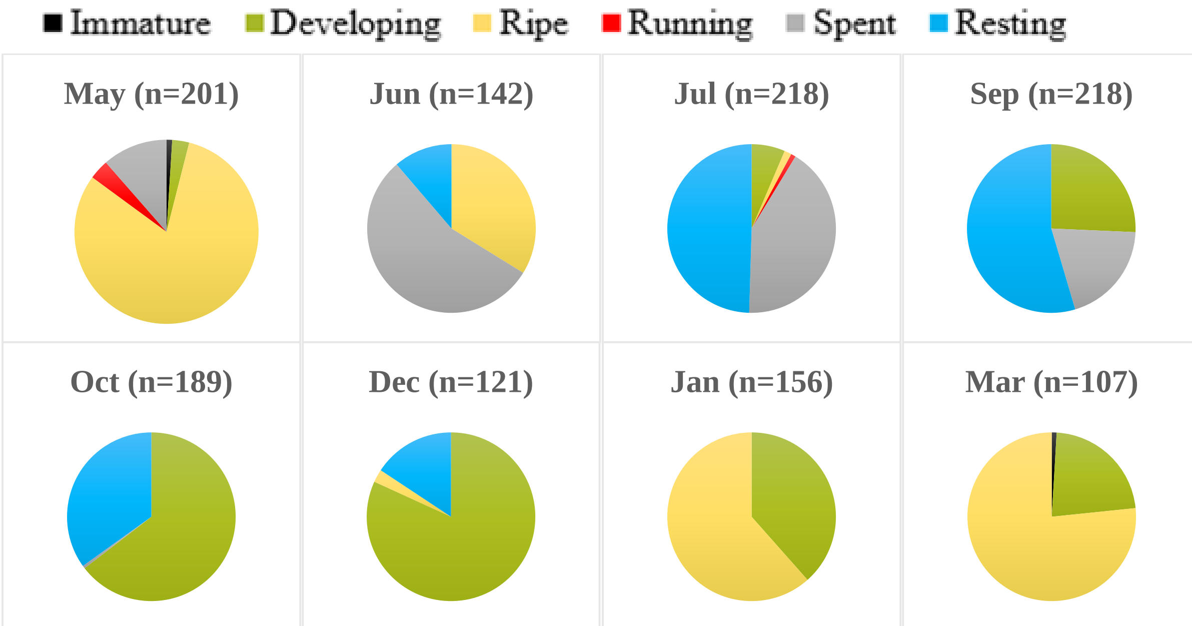


Figure 25 Seasonal maturity results of female yellowtail flounder in CAII for each month of the survey, highlighting the relative percentages of each stage. With the number of fish examined recorded in the legend for each month.

The results of the maturity staging for yellowtail flounder on Georges Bank indicate the peak spawning was similar to previous years from May through June. The 2012 survey showed that the majority of fish had spawned for the June survey trip, while the 2011 bycatch surveys identified fish in spawning condition in the May and June trips. These results are relatively consistent with the spawning period indicated by Collette and Klein-MacPhee (2002), who indicate peak spawning on Georges Bank occurs during April/May. Females first showed signs of development in September with some developing as early as July, and by December, both sexes were more than 90% developed or ripe.

Winter Flounder

The winter flounder sample size was 971 fish measured and staged for maturity, with 706 females and 265 males. The mean size of all females sampled was 42.85 cm, while 39.37 cm was the mean size for male winter flounder. Winter flounder were ripe in January and March. No female fish were observed in ripe and running condition. However, there were two males ripe and running in May 2013, one male ripe and running in December 2013, and four males ripe and running in March 2014. Most fish were visibly spent or resting beginning in June and then starting to develop in November (Figures 26 & 27 Table A-9).

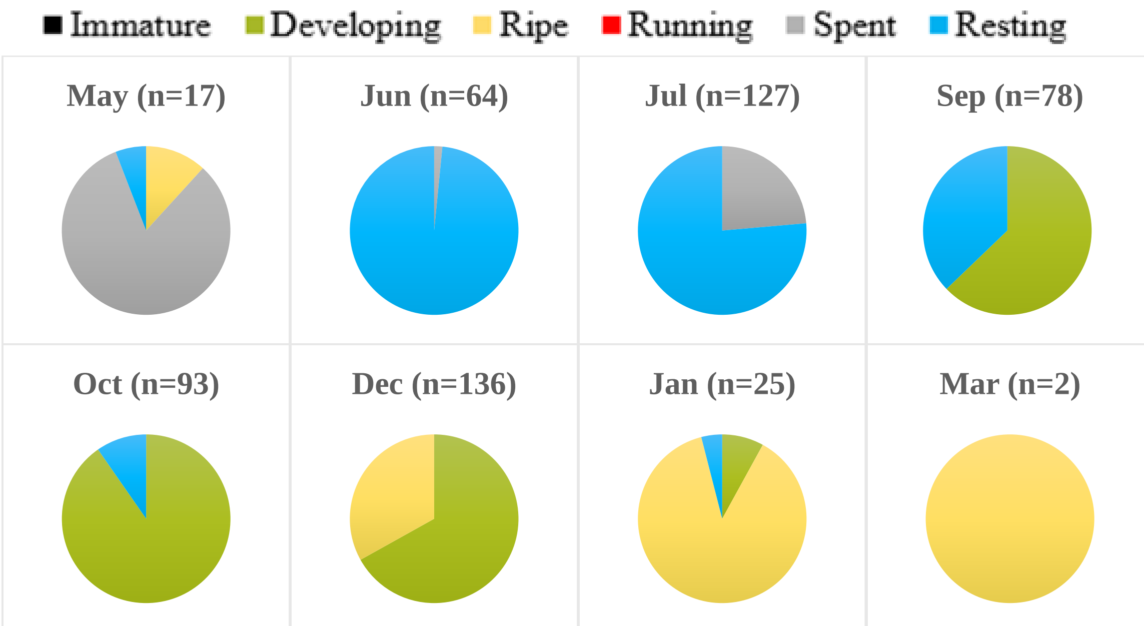


Figure 26. Seasonal maturity results of female winter flounder in CAI for each month of the survey. With the number of fish examined recorded in the legend for each month.

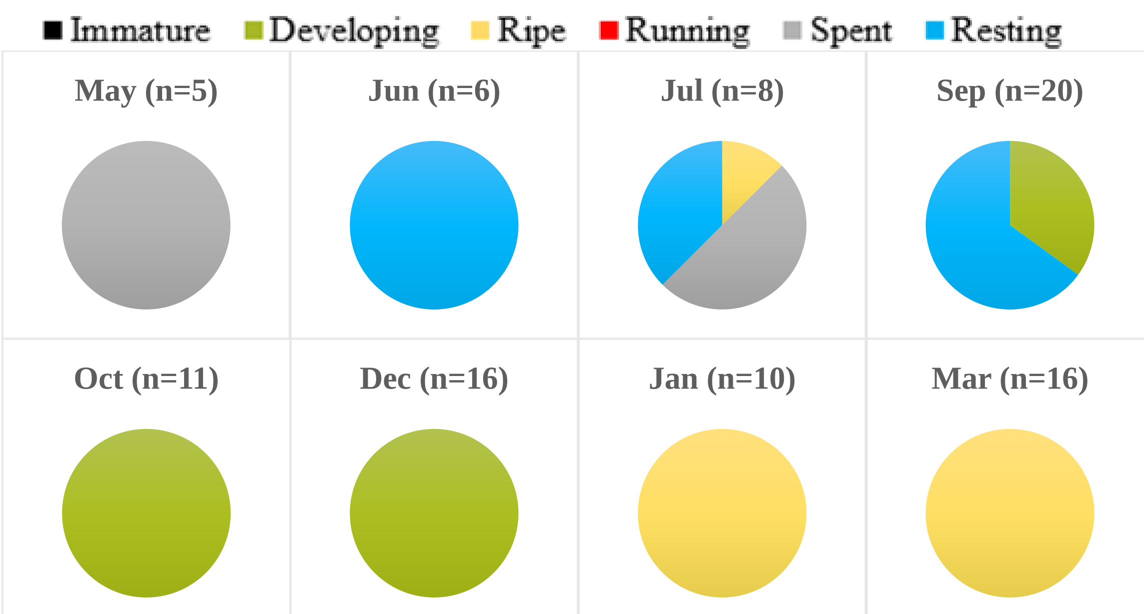


Figure 27. Seasonal maturity results of female winter flounder in CAII for each month of the survey. With the number of fish examined recorded in the legend for each month.

The maturity staging results were consistent with last year's results indicating winter flounder spawn on Georges Bank near March, with most fish visibly spent or resting beginning in June, and then starting to develop in September. These results are similar to those reported by Collette and Klein-MacPhee (2002), which indicates spawning time differs as you travel north along the coast but still occurs between December and March. It also appears that winter flounder are not present in the survey location during peak spawning season, No female winter flounder were observed to be ripe and running yet 7 males were observed to be in spawning condition.

The percentage of females for this survey year was 82% female for yellowtail and 73% female for winter flounder. The 2013 survey reported a higher percentage of females than the previous year's survey (yellowtail flounder 73% female, winter flounder 66% female), and the mean size of both females and males stayed the same.

Yellowtail Flounder Disease Study

During the May 2011 bycatch survey we identified suspected *Ichthyophonus* infections in yellowtail. *Ichthyophonus spp,* even at low levels, has been linked to high mortality events in various fish species (Mellengaard and Spanggaad, 1997). Yellowtail flounder samples collected on Brown's Bank, Nova Scotia in 1987 showed severe infection caused by a new protozoan species, *Ichthyophonus irregularis,* which has only been identified in yellowtail flounder (Rand, 1994; Rand et al., 2000) Sampling protocol was established on the seasonal bycatch survey in 2012 to confirm *Ichthyophonus* infection and better understand the prevalence, distribution, and effects this parasite may have on a vulnerable yellowtail population.

Yellowtail flounder were randomly selected from the catch throughout the survey for at-sea examination. After the yellowtail were sorted from the catch, they were weighed and measured. The peritoneal and pericardial cavities of each fish were opened and macroscopically examined for abnormalities. Each abnormality was noted, photographed and tissues were fixed in 10% neutral buffered formalin for histological evaluation.

The fish were classified into three groups based on macroscopic appearance: no observable abnormalities, macroscopic signs of *Ichthyophonus,* and lesions not characteristic of *Ichthyophonus* (Figure 28). Presence of *Ichthyophonus* was identified by off-white cysts and a whitish sheen to the serosal surface of the peritoneal organs and/or heart (Fish, 1934; McVicar, 1982). Tissues from animals with no observable lesions were not collected. Fixed tissues were trimmed and transferred into 70% ethanol solution, embedded in paraffin, and 6μm-sections were cut and stained with hematoxylin and eosin. Resulting slides were evaluated histopathologically.

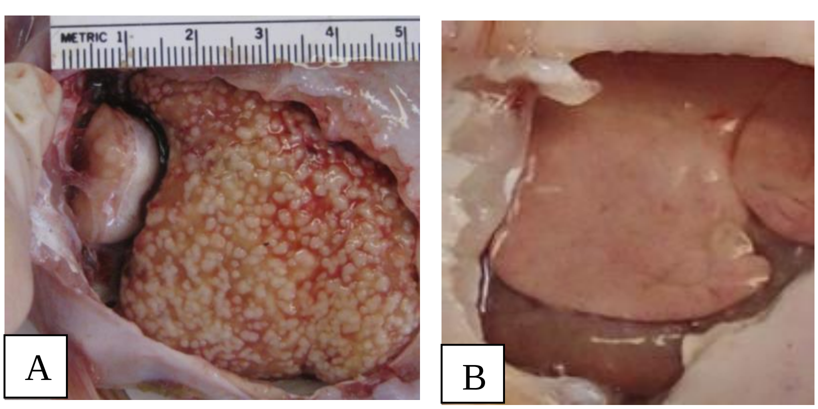


Figure 28. Macroscopic image of a severe *Ichthyophonus* infection, with the characteristic lesions spreading over the liver and throughout the heart (A). Compared with a liver with no *Ichthyophonus* infection (B)

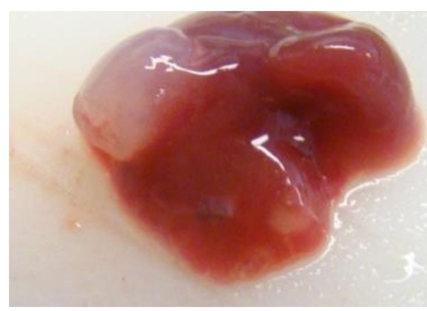
During the 2013 seasonal bycatch survey, 788 yellowtail flounder were examined for disease: 28% of the fish examined had no visible signs of *Ichthyophonus* or other substantial parasites, 70.1% had various parasites, and 1.9% of the fish had confirmed cases of *Ichthyophonus* infection. Including all samples for the entire time series from 2012, there was a 2.1% infection rate of *Ichthyophonus*. Microscopic examination showed that samples collected with nodules not identified as *Ichthyophonus* were due to a variety of other parasites, including larval nematodes and cestodes of which some were observed to be debilitating to the fish.

Flounders infected with *Ichthyophonus* were found throughout the sample area, thus infection rates do not appear to be associated with a specific geographic location on Georges Bank. It is possible that there is a seasonal component to the infections by *Ichthyophonus*, which could also be related to feeding behavior or abundance of carriers. During the 2013 bycatch survey year, there was a peak of 5 infections during the September trip. A peak was seen in the 2012 survey during the beginning of November with 8 infections observed.

All fish with high *Ichthyophonus* infection levels showed severe myocardial infections. These lesions would severely weaken the heart, resulting in severe limitation of the movement of the fish and thus death from predation or overexertion. No lesions were identified that indicated healing from damage caused by the infectious organism.

Histological results suggest that *Ichthyophonus* may spread quickly through tissues causing damage and resulting in mortality or debilitation. *Ichthyophonus* appeared to target organs with high blood flow such as the heart, liver, and gonads and often resulted in tissue necrosis and inflammation. All highly infected animals have shown severe myocardial infection, with myocarditis and both endo- and epicarditis (Figure 29). Further research is needed to determine how long the disease takes to spread from initial to lethal infection levels as well as to determine the extent of mortality due to *Ichthyophonus* infection.

Figure 29. Comparison of a heart severely infected with *Ichthyophonus* (left) and a healthy heart (right).



Lobster Catch

During the 2013 survey year a total of 368 lobsters were caught, ranging from 2 to 102 for each trip (Figure 30). For each lobster, carapace length, shell hardness, sex, presence of eggs, and the prevalence of shell disease was recorded. Gear-related damage was also evaluated for each lobster using the following criteria adapted from Smith and Howell (1987):

1. No damage - this included old damage characterized by healing tissue and the absence of bleeding.
2. Minor damage - chipped rostrum, loss of walking leg or autotomized claw (amputation at breaking plan).
3. Major damage - dead or crushed/broken body parts including claws.

The Smith and Howell (1987) study showed that lobsters with minor injuries did not experience delayed mortality during a 14-day observation period.

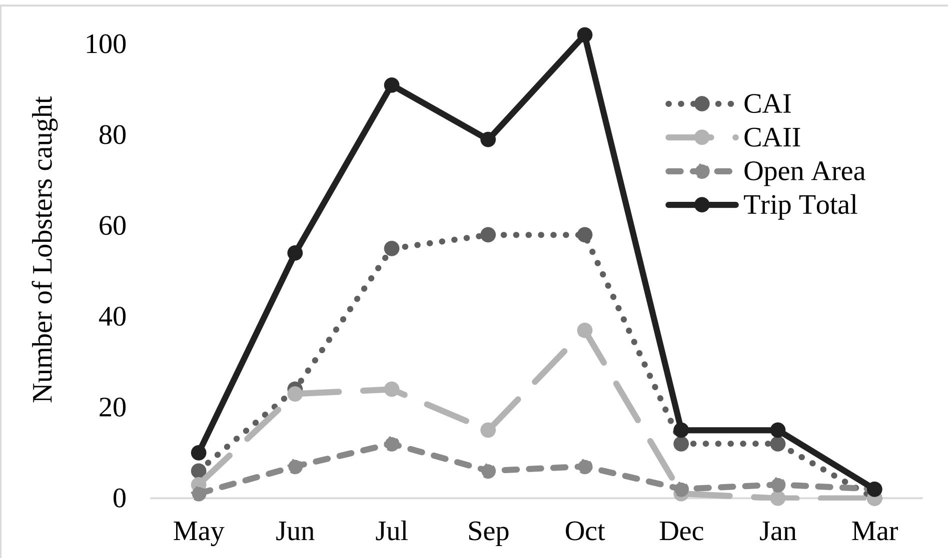


Figure 30. Total catch of lobsters for each survey trip (Solid Black) and broken up into each survey area.

Basic summary statistics were used to evaluate gear effect on lobster catch between the different areas in the survey. Overall there was no significant difference between gear types, but for CAII the TDD had a significantly lower lobster catch (Wilcoxon signed-rank test: all areas, p=0.25; CAII p=0.02, Table 8). Jamison and Campbell (1985) demonstrated that lobsters in rocky habitats tend to hide from scallop gear rather than attempt escape which may account for the differences seen in gear type by area. The study conducted by Jamison and Campbell (1985) used gulf rock drags, digby rock drags and gulf sweep chain drags, which are not used in the Georges Bank fishery, yet using SCUBA divers they showed that the majority of lobsters (88.3%) escaped or passed through their gear undamaged. This study used 3-inch rings with the dredges moving at an average of 4.3 knots in the Northumberland Strait, Canada.

Table 8. Lobster catch totals for each gear type, (New Bedford style dredge (NBD and turtle deflector dredge TDD) for the duration of this project. Significant values from the Wilcoxon signed-rank test shown in red.

	CAI	CAII	Open area	All areas
NBD	120	64	17	201
TDD	105	39	23	167
p value	0.76	0.02	0.42	0.25
w	7426	2107	435	282

While the fishing gear used for this project has no catchability estimates for lobster, it is assumed that the escape response should be similar to the Jamison and Campbell (1985) study and that the majority of lobsters encountered at the bottom escape undamaged. For all lobsters caught during this project, carapace length ranged from 46-208 mm with an average of 123 mm for males and 134 mm for females. A preliminary examination of level of damage by size frequency and location showed no distinct differences between damage classes or area (Figure 31 & 32).

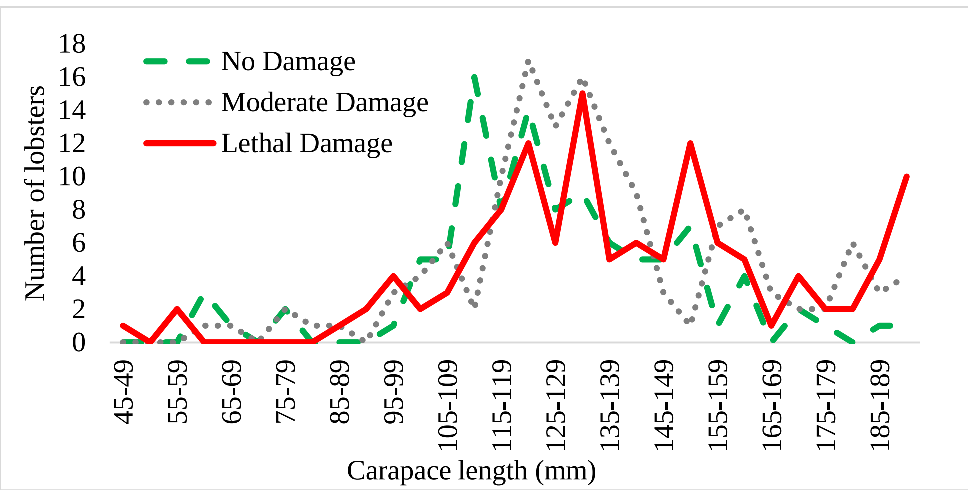


Figure 31. Size distribuiton for all lobsters caught during the 2103 bycatch survey categorized by damage level (Smith and Howell 1987)

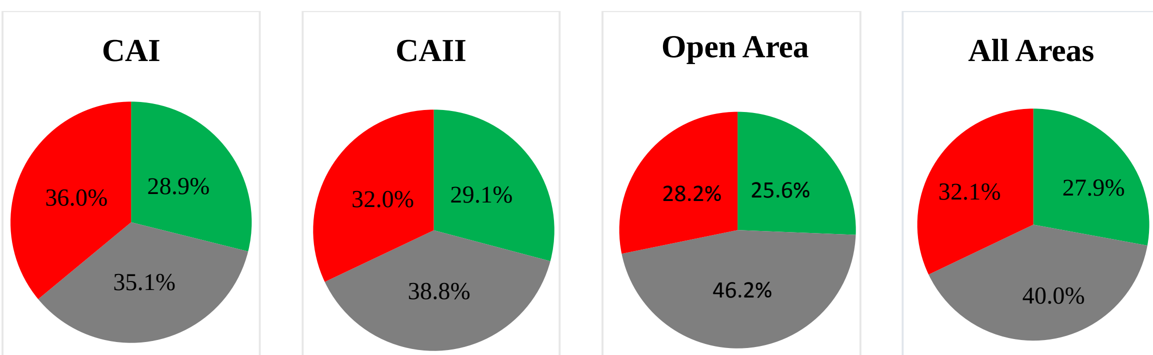


Figure 32. Damage by area and all areas grouped together. Red (top left) lethal damage, green (top right) no damage, and gray (bottom) moderate damage.

Abundance of lobsters peaked in October, which coincided with the peak of lobsters carrying eggs (Figure 33). We observed lobsters with in the molt stage B (soft as defined in Passano, 1960) during each survey trip, but our data showed the peak of soft and new shelled lobsters coinciding with their peak abundance in CAII (Figure 34). Abundance of females was generally much higher than males with a 5:1 female-to-male ratio.

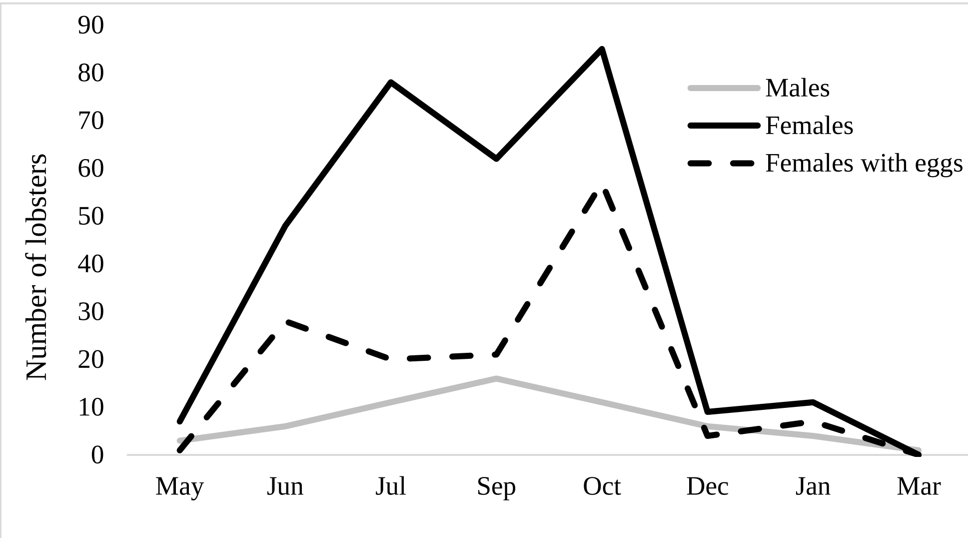


Figure 33. Total abundance of lobsters for each month of the survey trip broken down by sex and number of females with eggs.

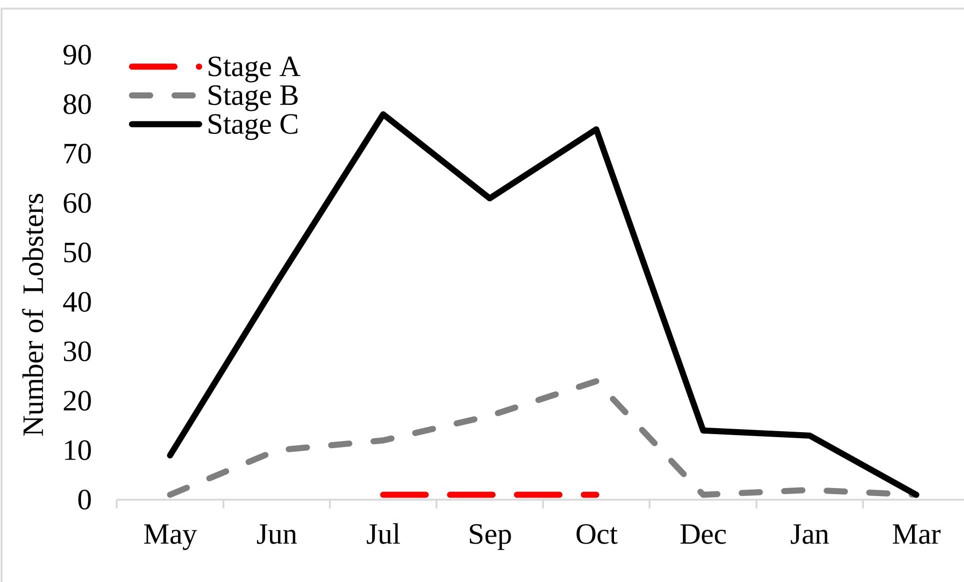


Figure 34. Total abundance of lobsters for each month of the survey trip categorized by molt stage; with A as new, B as soft, and C as hard shell (Passano, 1960)

Conclusion

This seasonal bycatch survey has generated an abundance of valuable information for improving bycatch reduction through gear design and mapping of seasonal fish distributions. Secondary but important studies have examined life histories of scallops and flatfish as well as scallop and yellowtail diseases. The surveys have also served as an important management resource for the scallop industry by effectively monitoring flatfish bycatch on Georges Bank. Data from the earlier bycatch surveys showed high yellowtail bycatch in the late summer and fall resulting in changes to the access area closures in Framework 24. CAII was closed from August 15th - November 15th rather than from February 1st - June 14th (NEFMC, 2013). Results from our yellowtail flounder data were also presented to the 2013 Transboundary Resources Assessment Committee for consideration while setting the benchmarks for the Georges Bank yellowtail flounder stock assessment (DeCelles et al 2014, Huntsberger and Smolowtiz, 2014, Winton et al. 2014).

Furthermore, the bycatch survey provides a means of collecting data to address contemporary management issues such as distribution and prevalence of bycatch species of new concern (e. g. windowpane flounder), habitat characteristics, and scallop meat discard rate.

For the 2013 survey, we met our primary project goal as well as our secondary goals. The data collected during this project reflected the previous year's results. The highest meat yield for scallops was in June, and during this same time period when meat yield was highest, primary bycatch species numbers were lowest for Closed Area II. Two fishing gears were compared, and the turtle deflector dredge with the shorter apron had equal scallop catch to the traditional New Bedford dredge, while having a reduced windowpane flounder catch in all areas and a reduced lobster catch in CAII.

The project design provided an opportunity to expand our sampling protocol to investigate aspects of the general biology of scallops and bycatch species, specifically seasonal distributions, maturity, growth, and disease. We have shown localized hot-spots of yellowtail flounder reoccurring each year in the northeast part of CAII during August and September and south of CAII in the early winter. We confirmed semiannual spawning for scallops in the survey area. Finally, we identified and monitored three diseases which may have an important impact on management for the fisheries.

The seasonal bycatch survey in and around the scallop access areas of Georges Bank has been very successful. The survey will continue in 2015 on northern Georges Bank and will monitor seasonal changes in scallop meat yield and flatfish bycatch as well as continue biological sampling in an area with very limited data.

Management Application

New England Fishery Management Council (NEFMC). 2012. Framework 24 to the Scallop FMP and Framework 49 to the Multispecies FMP including a draft environmental assessment (EA), an initial regulatory flexibility analysis and stock assessment and fishery evaluation (SAFE Report). New England Fishery Management Council, Newburyport, MA.

Publications

Barkley, A. S., S. X. Cadrin. 2012. Discard mortality estimation of yellowtail flounder using reflex action mortality predictors. Transactions of the American Fisheries Society. 141: 638-644.

Thompson, K.J., S. D. Inglis, K.D.E. Stokesbury. 2014. Identifying Spawning Events of the Sea Scallop *(Placopecten magellanicus*) on Georges Bank. Journal of Shellfish Research, 33:1, 77–87.

Drafts of Publications

Grimm C., C. Huntsberger, K. Markey, S. Inglis, and R. Smolowtiz. *In review.* Identification of *Mycobacterium placopecteni spp. nov* as the Causative Agent of 1 Orange Nodular Lesions in the Atlantic Sea Scallop, *Placopecten magellanicus.* Submitted to J. of Disease of Aquatic Organisms April 26, 2015.

Winton, M., K. Thompson, D. Rudders, G. DeCelles, C. Huntsberger, K. Goetting, R. Smolowitz. Optimizing meat yield and minimizing bycatch in the Georges Bank sea scallop fishery. *Draft in prep*

2014 YT TRAC Working Papers

DeCelles, G., K. Thompson, S. Cadrin. 2014. Estimates of yellowtail flounder biomass on Georges Bank derived from a seasonal dredge survey. Transboundary Resource Assessment Committee (TRAC) Working Paper 2014: 22 p.

Huntsberger, C., R. Smolowitz. 2014. Prevalence of *Ichthyophonus sp.* in yellowtail flounder sampled during the seasonal bycatch survey on Georges Bank. Transboundary Resource Assessment Committee (TRAC) Working Paper 2014: 20 p.

Winton, M., K. Thompson, C. Huntsberger, R. Smolowitz. 2014. Seasonal distribution of yellowtail flounder in Georges Bank scallop access areas as inferred from the seasonal bycatch survey. Transboundary Resource Assessment Committee (TRAC) Working Paper 2014: 17 p.

Presentations

DeCelles, G., M. Winton, K. Thompson, S. Cadrin. Abundance and distribution of yellowtail flounder on Georges Bank. 14th Flatfish Biology Conference. December 3-4 2014. Westbrook, CT.

Goetting, K., A. Barkely, S. Inglis, K. Thompson, D. Rudders, and R. Smolowitz. Contributing to management decisions through a comprehensive scallop survey on Georges Bank. 19th International Pectinid Workshop. Florianopolis, Brazil. April 10-16, 2013.

Huntsberger, C. Summary of scallop disease and lobster catch from the seasonal bycatch survey. Joint scallop planning and development team and advisory panel meeting. Warkwick, RI, May 13, 2015.

Huntsberger, C., R. Smolowitz. 2014. Description and prevalence of *Ichthyophonus* in yellowtail flounder on Georges Bank. 144th Annual Meeting of the American Fisheries Society. Quebec, Canada. August 17-21, 2014.

Inglis, S., A. Kristmundsson, K.D.E. Stokesbury. What causes gray meat in the Atlantic sea scallop in Georges Bank closed areas? Sea Scallop Planning Development Team. New Bedford, MA. April 9, 2014.

Inglis, S., A. Kristmundsson, K.D.E. Stokesbury. What causes gray meat in the Atlantic sea scallop in Georges Bank closed areas? 144th Annual Meeting of the American Fisheries Society. Quebec, Canada. August 17-21, 2014.

Smolowitz, R., C. Huntsberger, K. Goetting, R. Smolowitz. *Ichthyophonus* species effects on yellowtail flounder in special access areas on Georges Bank. MFI Workshop on Incorporating Environmental Change in Assessments and Management. Fairhaven, MA. May 7-8, 2013.

Thompson, K. Sex Down Under: The Secret Life of Sea Scallops. 3rd Annual Three Minute Thesis Competition at the University of Massachusetts Dartmouth. North Dartmouth, MA. May 10, 2013. Received 2nd place award.

Thompson, K., C. Huntsberger, G. DeCelles. Results from the seasonal bycatch survey. Invertebrate Subcommittee. Woods Hole, Ma. March 17, 2014.

Thompson K., S. D. Inglis, K. D. E. Stokesbury. Identifying Spawning Events of the Sea Scallop, *Placopecten magellanicus*, on Georges Bank. 104th Annual Meeting of the National Shellfisheries Association. Seattle, WA. March 25-29, 2012. Received 2012 Gordon Gunter Award.

Thompson K., S. D. Inglis, K. D. E. Stokesbury. Identifying Spawning Events of the Sea Scallop, *Placopecten magellanicus*, on Georges Bank. 19th International Pectinid Workshop. Florianopolis, Santa, Catarina, Brazil. April 10-16, 2013.

Thompson, K. S. D. Inglis, K.D.E. Stokesbury. Seasonal bycatch survey of the sea scallop access areas on Georges Bank. 144th Annual Meeting of the American Fisheries Society. Quebec, Canada. August 17-21, 2014.

Wright, B., C. O'Keefe, G. DeCelles, S. Cadrin. Factors of yellowtail flounder bycatch in the sea scallop fishery. 144th Annual Meeting of the American Fisheries Society. Quebec, Canada. August 17-21, 2014.

References

Akaike H. 1973. Information theory as an extension of the maximum likelihood principle. In Second international symposium on information theory. Edited by B.N. Petrov and F. Csaki. Akademiai Kiado, Budapest, Hungary, pp. 267-281.

Almeida, F. T., T. Sheehan and R. Smolowitz. 1994. Atlantic sea scallop, *Placopecten magellanicus*, maturation on Georges Bank during 1993. NEFSC Ref. Doc., pp 94-13.

Bachman, M.S. 2009. Determinants of Yellowtail Flounder Bycatch in the Closed Area II Scallop Access Fisheries on Georges Bank. University of Massachusetts School of Marine Sciences. Masters Thesis.

Blanchard JL, Maxwell DL, and Jennings S. 2008. Power of monitoring surveys to detect abundance trends in depleted fish populations: the effects of density-dependent habitat use, patchiness, and climate change. ICES Journal of Marine Science 65:111-120.

Barber, B. J. and N. J. Blake. 2006. Reproductive physiology. In: Shumway SE (ed). Scallops: biology, ecology and aquaculture. Elsevier, Amsterdam, pp 377-428.

Bigelow, H. B. and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv. Fish. Bull. 53, 577 p.

Brust, J. and Belcher, C., 2000. Sampling Methodology Review. Chapter 9: Fisheries Stock Assessment User's Manual. Atlantic States Marine Fisheries Commission Special Report No. 69.

Burnett, J., L. O'Brien, R. Mayo, J. Darde and M. Bohan. 1989. Finfish maturity sampling and classification schemes used during Northeast Fisheries Center bottom trawl surveys, 1963-89. NOAA Technical Memorandum NMFS-F/NEC-76: 14 pp.

Caddy, J. F. 1989. A perspective on the population dynamics and assessment of scallop fisheries with special reference to the sea scallop, *Placopecten magellanicus* (Gmelin). In: JF Caddy (ed.). Marine Invertebrate Fisheries: Their Assessment and Management. John Wiley & Sons, Inc., pp 559-589.

Cadigan, N.G., S.J. Walsh and W. Brodie. 2006. Relative efficiency of the *Wilfred Templeman* and *Alfred Needler* research vessels using a Campelen 1800 shrimp trawl in NAFO Subdivisions 3Ps and divisions 3LN. Can Sci Advis Secret Res Doc 2006/085; 59 pp.

Cadigan, N.G. and J. J. Dowden. 2009. Statistical inference about relative efficiency of a new survey protocol, based on paired-tow survey calibration data. Fish. Bull. 108:15-29.

Cadrin, S.X., Melgey, J., and Stokesbury, K.D.E. 2014. Abundance of yellowtail flounder in the access area of closed area 2 on Georges Bank in June 2008 from a large-scale Petersen tagging study. Transboundary Resource Assessment Committee, Working Paper 2014/24. 21p.

Chen, C., R.C. Beardsley and G. Cowles. 2006. An unstructured-grid, finite-volume coastal ocean model (FVCOM) system. Oceanography, 19(1): 78-89.

Chute, A. S., S. C. Wainright and D. R. Hart. 2012. Timing of shell ring formation and patterns of shell growth in the sea scallop Placopecten magellanicus based on stable oxygen isotopes. J. Shellfish Res. 31:649–662.

Colette, B. B., and G. Klein-MacPhee (Eds). 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine. Third Edition. Smithsonian Institution Press, Washington, DC, 748 p.

Craig, H. 1965. The measurement of oxygen isotope paleotemperatures. *In* "Stable Isotopes in Oceanographic Studies and Paleotemperatures" (E. Tongiorgi, Ed.), pp. 161–182. Consiglio Nazionale delle Richerche, Laboratorio de Nucleare, Pisa, Italy.
Dibacco C, Robert G, Grant J. 1995. Reproductive cycle of the sea scallop, *Placopecten*

magellanicus (Gmelin, 1791), on northeastern Georges Bank. Journal of Shellfish Research, 14(1): 59-69.
DeCelles, G., Thompson, K., and Cadrin, S. Estimates of yellowtail flounder biomass on Georges Bank derived from a seasonal dredge survey. Transboundary Resource Assessment Committee, Working Paper 2014/20. 24p.
DiBacco C., G. Robert, J. Grant. 1995. Reproductive cycle of the sea scallop, *Placopecten magellanicus* (Gmelin, 1791), on northeastern Georges Bank. J Shellfish Res, 14:59-69.
Epstein, S., R. Buchsbaum, H. A. Lowenstam and H. Curey. 1953. Revised carbonate-water isotopic temperature scale. GSA Bulletin Vol. 64, No. 11:1315-1326.
Fish, F. 1934. A fungus Disease in the fishes of the gulf of Maine. Parasitology. 26:1-16.
Grimm C., C. Huntsberger, K. Markey, S. Inglis, and R. Smolowtiz. *In review. I*dentification of *Mycobacterium placopecteni spp. nov* as the Causative Agent of 1 Orange Nodular Lesions in the Atlantic Sea Scallop, *Placopecten magellanicus.* Submitted to J. of Disease of Aquatic Organisms April 26, 2015.
Goewert, A.E. and D. Surge. 2008. Seasonality and growth patterns using isotope sclerochronology in shells of the Pliocene scallop *Chesapecten madisonius*. Geo-Mar Lett 28:327-338.
Hart, D.R. and A.S. Chute. 2004. Essential Fish Habitat Source Document: Sea Scallop, Placopecten magellanicus, Life History and Habitat Characteristics, Second Edition. NOAA Technical Memorandum NMFS-NE-189 (21pp).
Hennen, D. and D. R. Hart. 2012. Shell Height-to-Weight relationships for Atlantic sea scallops (*Placopecten magellanicus*) in offshore U.S. waters. JSR. 34:1133-1144.
Hilborn R, and Walters CJ. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York.
Holst, R. and A. Revill. 2009. A simple statistical method for catch comparison studies. Fisheries Research. 95: 254-259.
Huntsberger, C., R. Smolowitz. 2014. Prevalence of *Ichthyophonus sp.* in yellowtail flounder sampled during the seasonal bycatch survey on Georges Bank. Transboundary Resource Assessment Committee (TRAC) Working Paper 2014: 20 p.
Inglis, S.D. and K.D.E.Stokesbury. 2014. "What Causes Gray Meat in the Atlantic Sea Scallop, *Placopecten magellanicus*", Scallop RSA Final Report. NOAA Grant: NA12NMF4540036.
Jamison, G. and A. Campbell. 1985. Sea scallop fishing impact on American lobster in the Gulf of St. Lawrence. Fishery Bulletin 83:575-586
Jones, D. S. and I. R. Quitmyer. 1996. Marking time with bivalve shells: Oxygen isotopes and the season of annual increment formation. Palaios, Vol. 11, No. 4:340-346.
Krantz, D. E., D. S. Jones, and D. F. Williams. 1984. Growth rates of the sea scallop, *Placopecten magellanicus*, determined from the 18O/16O record in shell calcite. Biol. Bull., Vol. 167: 168.
Legault, C.M., Alade, L., Gross, W.E., and Stone, H.H. 2013. Stock assessment of Georges Bank Yellowtail Flounder in 2013. Transboundary Resource Assessment Committee Working Paper 2013/: 138p.
Littell, R.C., G. A. Milliken, W. Stroup, R. Wolfinger and W.O. Schabenberger. 2006. SAS for Mixed Models (2nd ed.). Cary, NC. SAS Institute Inc.
Martin, M., and Legault, C.M. 2014. The August 2013 flatfish survey on Georges Bank. Transboundary Resource Assessment Committee, Working Paper 2014/23 (revised). 26p.

McVicar, A. H. 1982. Ichthyophonus infection of fish. In: Roberts, R. J. (ed.) Microbial disease of fish. Academic Press. London, p 243-269.
Medcof, J. C. and N. Bourne. 1964. Causes of mortality of the sea scallop, Placopecten magellanicus. J. Fish. Res. Bd. Can. 53:33-50.
Mellergaard, S. and B. Spanggaard. 1997. An *Ichthyophonus hoferi* epizootic in herring in the North Sea, the Skagerrak, the Kattegat, and the Baltic Sea. Dis Aquat Org. 28: 191-199.
Millar, R.B., M.K. Broadhurst and W.G. Macbeth. 2004. Modeling between-haul variability in the size selectivity of trawls. Fisheries Research. 67:171-181.
Milke, L.M., Bricelj, V.M. and C.C. Parrish 2004. Enhanced production of postlarval sea scallops, Placopecten magellanicus, on binary microalgal diets, with emphasis on lipids and polyunsaturated fatty acids. Aquaculture, 234:293–317.
New England Fishery Management Council (NEFMC). 2013. Framework 24 to the Scallop Fishery Management Plan and Framework 49 to the Multispecies FMP. February 2013.
Northeast Fisheries Science Center. 2010. 50th Northeast Regional Stock Assessment Workshop (50th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 10-17; 844 p.
NMFS. 2007. Appendix B5: Selectivity of commercial sea scallop dredges with 4” rings. In Report of the 45th Northeast Regional Stock Assessment Workshop. NOAA/NMFS/NEFSC. pp. 287-292.
O’Keefe, C. E., G. R. DeCelles. 2013. Forming a partnership to avoid bycatch. Fisheries 38: 434-444.
Owen, R., H. Kennedy and C. Richardson. 2002. Isotopic partitioning between scallop shell calcite and seawater: Effect of shell growth rate Geochimica et Cosmochimica Acta, Vol. 66, No. 10:.1727-1737.
Passano, L M. 1960. Molting and its control. Pp 473-536 in Physiology of crustacean Volume 1. Watermen ed. Academic Press, New York.
Peterson, B. J. and B. Fry. 1987. Stable Isotopes in Ecosystem studies. Ann. Rev. Ecol. Syst., Vol. 18: 293-320.
Rand, T.. 1994. An Unusual form of *Ichthyophonus hoferi* (Ichthyophonales:Ichthyopohonaceae) from yellowtail flounder *Limanda ferruginea* from the Nova Scotia shelf. Dis Auat. Org. 18: 21-28
Rand, T., K. White, J. Cannone, R. Gutell, C. Murphy, and M. Ragan. 2000. *Ichthyophonus irregularis sp.* nov. from the yellowtail flounder *Limanda ferruginea* from the Nova Scotia shelf. Dis Aquat. Org. 41: 31-36.
Sarro, C.L. and K.D.E. Stokesbury. 2009. Spatial and temporal variation in the shell height/meat weight relationship of the sea scallop *Placopecten magellanicus* in the Georges Bank fishery. Journal of Shellfish Research 28(3): 497-503.
Scallop PDT, 2012. Development of GB Access Area Seasonal Restriction Alternatives. Document #2A. Prepared for the November 13th-15th Scallop PDT Meeting. 26p.
Smith, E. and P. Howell. 1987. The effects of bottom trawling on American lobsters *Homarus americanus*, in Long Island Sound. Fishery Bulletin. 85:737-744.
Smolowtiz, R. J. H. Miliken, and M. Weeks. 2012. Design, Evolution, and Assessment of a sea turtle deflector dredge for the U.S. northwest Atlantic sea scallop fishery: Impacts on fish bycatch. N Amer. J. Fisheries Management. 35: 65-76.
Sokal, R.R., and Rohlf, F.J., 2001. Biometry, Third Edition. W.H. Freeman and Company, New York.
Stewart, P.L. and S.H. Arnold. 1994. Environmental requirements of the sea scallop

(Placopecten magellanicus) in eastern Canada and its response to human impacts. Can. Tech. Rep. Fish. Aquat. Sci. 2005:1-36.
Tan, F.C., D. Cai and D. L. Roddick. 1988. Oxygen isotope studies on sea scallops, *Placopecten magellanicus*, from Browns Bank, Nova Scotia. J. Fish. Aquat. Sci. Vol. 45. pp. 1378 1396.
Thompson, K.J., S. D. Inglis, K.D.E. Stokesbury. 2014. Identifying Spawning Events of the Sea Scallop *(Placopecten magellanicus*) on Georges Bank. Journal of Shellfish Research, 33:1, 77–87.
Wigley, S. E., H. M. McBride and N. J. McHugh. 2003. Length-weight relationships for 74 fish species collected during NEFSC research vessel bottom trawl surveys, 1992-9. NOAA Tech Memo NMFS NE 171.
Winton, M., K. Thompson, C. Huntsberger, R. Smolowitz. 2014. Seasonal distribution of yellowtail flounder in Georges Bank scallop access areas as inferred from the seasonal bycatch survey. Transboundary Resource Assessment Committee (TRAC) Working Paper 2014: 17 p.
Zar, J. H. 2010. Biostatistical analysis. Fifth Edition. Upper Saddle River, NJ: Prentice Hall. 944 pp.

Appendix A
Additional general information

Table A-1. Gear Specifications used during the 2013 bycatch survey

Head Bail Design	Turtle Deflector Dredge	New Bedford Dredge
Head Bale width	15 Feet	15 Feet
Dredge ID	TDD	NBD
Type of Chain for Turtle Mat	3/8" Grade 70	3/8" Grade 70
Up and Downs	13	13
Tickler Chain	9	9
Type of Chain for Sweep	Long Link Grade 80	Long Link Grade 80
Number of Links in Sweep	121 long links	121 long links
Chain Sweep Hanging	12 link dog chain for the first ring 6 links in; 9 link dog chains every 4 links and 2 rings with 11 link dog chains in the corners; every 4 rings in the bag (6,4,4,2,4…)	12 link dog chain for the first ring 8 links in; 9 link dog chain every 4 links and 2 links with 11 link dog chain in the corners; 4 in the bag (8,4,2,4…)
Twine Top	2:1 with two in the sides	3:1 with two in the sides
Diamonds	14	14
Skirt	2X28 or 2X40 with dog chain	3X28 or 3X40 with shackles
Sides	6X18 or 6X20	6X17 or 6 X20
Apron	8 X 40	10 X 40
Bag	10 X 40	9 X 40
Chaffing Gear	Sewn in three rows down from the sweep for the bag and on the diamonds	Sewn in three rows down from the sweep for the bag and on the diamonds
Club Stick	20 link dog chains	20 link dog chains

Table A-2. Species sampled and measured during the 2013 bycatch survey trip. Counts only, no measurements were taken on unclassified skate.

Common Name	Scientific Name
Invertebrates	
Sea Scallop	*Placopecten magellanicus*
American Lobster	*Homarus Americanus*
Flatfish	
Yellowtail Flounder	*Limanda ferruginea*
Winter Flounder	*Pseudopleuronectes americanus*
Windowpane Flounder	*Scophthalmus aquosus*
Summer Flounder (Fluke)	*Paralichthys dentatus*
Fourspot Flounder	*Paralichthys oblongus*
American Plaice	*Hippoglossoides platessoides*
Gray Sole	*Glyptocephalus cynoglossus*
Roundfish	
Haddock	*Melanogrammus aeglefinus*
Atlantic Cod	*Gadus morhua*
Monkfish	*Lophius americanus*
Spiny Dogfish	*Squalus acanthias*
Skates	
Barndoor Skates	*Dipturus laevis*
Unclassified Skate	*Leucoraja erinacea*
Unclassified Skate	*Leucoraja ocellata*

Table A-3. Survey coverage, mean yellowtail flounder catch rates, and estimates of area swept biomass in each survey strata across the eight trips that were sampled.

Sampling Dates	Area	# of Stations	Area Sampled (km2)	Mean Yellowtail Flounder Catch (kg/tow)	Yellowtail Flounder Density (kg/km2)	Yellowtail Flounder Biomass (mt)
May Trip 1	CAI	31	1201.1	0.27	53.0	62.7
	CAII	30	2844.6	1.33	263.9	738.7
	Open	30	2844.6	1.13	213.7	598.2
	Sum	**91**	**6890.3**			**1445.3**
June Trip 2	CAI	31	1201.1	0.62	124.6	145.6
	CAII	30	2844.6	0.95	189.2	529.7
	Open	30	2844.6	0.78	154.3	431.9
	Sum	**91**	**6890.3**			**1107.2**
July Trip 3	CAI	31	1201.1	0.42	87.1	102.9
	CAII	30	2844.6	2.3	452.3	1265.8
	Open	30	2844.6	0.13	24.9	69.6
	Sum	**91**	**6890.3**			**1438.4**
September Trip 4	CAI	31	1201.1	0.65	129.8	153.4
	CAII	30	2844.6	5.57	1104.0	3090.5
	Open	30	2844.6	0.4	78.0	218.3
	Sum	**91**	**6890.3**			**3462.1**
October Trip 5	CAI	31	1201.1	0.27	54.3	64.2
	CAII	30	2844.6	4.44	826.5	2313.3
	Open	30	2844.6	1.46	273.7	766.2
	Sum	**91**	**6890.3**			**3143.6**
December Trip 6	CAI	31	1201.1	0.45	92.7	109.6
	CAII	30	2844.6	1.71	347.0	971.4
	Open	30	2844.6	0.86	174.2	487.4
	Sum	**91**	**6890.3**			**1568.4**
January Trip 7	CAI	31	1201.1	0.14	27.7	32.8
	CAII	30	2844.6	2.68	547.6	1532.9
	Open	30	2844.6	1.95	385.9	1080.3
	Sum	**91**	**6890.3**			**2645.9**
March Trip 8	CAI	31	1201.1	0.12	23.6	27.9
	CAII	30	2844.6	1.52	301.1	842.9
	Open	30	2844.6	0.66	131.3	367.6
	Sum	**91**	**6890.3**			**1238.3**

Table A-4. Sensitivity of yellowtail flounder biomass estimates to the assumed catchability value of the New Bedford style dredge. All biomass values are in metric tons (mt). Bold values indicate the catchability value that was used in this report and presented to the 2014 Empirical Assessment for Georges Bank yellowtail flounder (DeCelles et al., 2014).

Sampling		Assumed value of q							
Dates	Area	1	0.8	0.6	0.5	0.4	0.3	**0.248**	0.1
April Trip 1	CA1	15.5	19.4	25.9	31.1	38.8	51.8	62.7	155.4
	CA2	259.4	324.2	432.3	518.7	648.4	864.6	1045.8	2593.7
	SWP	83.5	104.4	139.2	167.1	208.8	278.5	336.8	835.4
	Sum	358.4	448.1	597.4	716.9	896.1	1194.8	**1445.3**	3584.4
June Trip 2	CA1	36.1	45.1	60.2	72.2	90.2	120.3	145.6	361.0
	CA2	131.4	164.2	219.0	262.7	328.4	437.9	529.7	1313.7
	SWP	107.1	133.9	178.5	214.2	267.8	357.0	431.9	1071.1
	Sum	274.6	343.2	457.6	549.2	686.5	915.3	**1107.2**	2745.9
July Trip 3	CA1	25.5	31.9	42.5	51.1	63.8	85.1	102.9	255.3
	CA2	313.9	392.4	523.2	627.8	784.8	1046.4	1265.8	3139.2
	SWP	17.3	21.6	28.8	34.5	43.2	57.6	69.6	172.7
	Sum	356.7	445.9	594.6	713.5	891.8	1189.1	**1438.4**	3567.3
September Trip 4	CA1	38.0	47.6	63.4	76.1	95.1	126.8	153.4	380.5
	CA2	766.4	958.0	1277.4	1532.9	1916.1	2554.8	3090.5	7664.3
	SWP	54.1	67.7	90.2	108.3	135.3	180.4	218.3	541.3
	Sum	858.6	1073.3	1431.0	1717.2	2146.5	2862.0	**3462.1**	8586.1
October Trip 5	CA1	15.9	19.9	26.5	31.8	39.8	53.1	64.2	159.2
	CA2	573.7	717.1	956.2	1147.4	1434.2	1912.3	2313.3	5736.9
	SWP	190.0	237.5	316.7	380.0	475.0	633.4	766.2	1900.1
	Sum	779.6	974.5	1299.4	1559.2	1949.0	2598.7	**3143.6**	7796.2
December Trip 6	CA1	27.2	34.0	45.3	54.4	67.9	90.6	109.6	271.8
	CA2	240.9	301.1	401.5	481.8	602.3	803.1	971.4	2409.2
	SWP	120.9	151.1	201.5	241.8	302.2	402.9	487.4	1208.8
	Sum	389.0	486.2	648.3	778.0	972.4	1296.6	**1568.4**	3889.8
January Trip 7	CA1	8.1	10.2	13.5	16.2	20.3	27.1	32.8	81.2
	CA2	380.1	475.2	633.6	760.3	950.4	1267.2	1532.9	3801.5
	SWP	267.9	334.9	446.5	535.8	669.8	893.0	1080.3	2679.0
	Sum	656.2	820.2	1093.6	1312.4	1640.4	2187.3	**2645.9**	6561.8
March Trip 8	CA1	6.9	8.6	11.5	13.8	17.3	23.0	27.9	69.1
	CA2	209.0	261.3	348.4	418.1	522.6	696.8	842.9	2090.4
	SWP	91.2	113.9	151.9	182.3	227.9	303.9	367.6	911.6
	Sum	307.1	383.9	511.8	614.2	767.8	1023.7	**1238.3**	3071.1

Table A-5. Bottom water temperature in Closed Area I by station from May 2013 through March 2014.

Station	Depth (m)	May '13	Jun '13	Jul '13	Sep '13	Oct '13	Dec '13	Jan '14	Mar '14
101	71	7.44	5.82	7.74	10.67	11.29	9.48	6.88	5.39
102	70	7.4	6.03	8.29	10.74	11.6	9.53	6.91	5.4
103	65	7.48	6.89	9.86	14.02	13.25	9.81	6.88	5.33
104	63	7.53	6.7	11.41	13.96	13.25	9.84	6.88	5.34
105	65	7.33	7	8.12	11.96	14.1	8.98	6.92	5.33
106	60	7.46	8.16	9.36	12.6	14.41	9.37	6.96	5.37
109	78	6.73	6.73	6.2	9.3	12.3	8.4	6.86	5.17
110	65	7.31	8.42	6.45	12.15	14.31	9.1	6.86	5.17
111	61	7.4	9.38	8.61	14.03	14.56	9.67	6.99	5.21
112	57	7.46	10.52	10.35	14.68	14.67	10.14	7.18	5.25
115	85	6.8	6.03	6.4	11.98	11.9	8.7	6.79	5.27
116	70	6.94	6.8	6.68	11.56	13.54	9.97	6.89	5.23
117	66	7.34	8.06	7.75	14.05	14.59	10.28	7.09	5.24
118	58	7.45	8.82	8.72	15.05	14.66	10.42	7.42	5.27
119	58	7.52	10.32	12.49	16.27	14.76	10.44	7.44	5.23
122	75	6.81	6.97	6.82	11.18	13.6	9.82	6.79	4.83
123	65	6.91	7.81	7.78	13.31	14.86	10.18	6.84	4.96
124	61	6.87	8.5	9.48	15.03	15	10.26	6.91	5.12
125	60	7.09	8.72	9.36	15.59	14.92	10.78	7.18	5.19
126	57	7.11	9.42	12.38	16.03	14.91	10.92	7.35	5.17
127	54	7.15	10.73	13.33	16.17	14.98	11.08	7.6	5.17
128	49	7.22	11.81	16.32	17.08	15.08	11.17	7.67	5.16
129	45	7.23	11.87	16.32	17.22	15.38	11.23	7.73	5.11
131	61	7.26	10.56	11.55	14.1	15.04	11.12	7.05	5.19
132	58	7.23	11.1	13.57	15.75	14.91	11.29	7.26	5.18
133	59	7.25	11.27	14.32	16.67	14.84	11.32	7.5	5.17
134	52	7.27	11.77	15.58	17.15	15.07	11.23	7.86	5.12
135	49	7.27	12.12	16.32	17.18	15.36	11.34	7.91	5.12
136	46	7.29	12.21	16.6	17.09	15.41	11.32	7.82	5.07
137	65	7.27	9.44	12.72	13.89	14.86	10.92	7	5.22
138	67	7.28	9.97	13.3	14.16	14.9	11.07	7.05	5.26
Average		**7.2**	**9.0**	**10.8**	**14.2**	**14.3**	**10.3**	**7.2**	**5.2**

Table A-6. Bottom water temperature in Closed Area II by station from May 2013 through March 2014.

Station	Depth (m)	May '13	Jun '13	Jul '13	Sep '13	Oct '13	Dec '13	Jan '14	Mar '14
204	61	6.78	10.2	11.74	13.71	13.34	9.94	6.4	5.22
205	64	6.66	9.91	11.67	12.48	13.38	10.54	6.47	5.16
206	64	6.54	9.18	9.76	12.26	13.36	10.28	6.58	5.23
207	74	6.54	9.02	9.89	10.82	11.69	9.99	6.64	5.25
211	61	6.68	9.58	11.11	12.81	12.92	10.25	6.5	5.07
212	64	6.58	9.43	10.97	12.91	12.54	10.55	6.58	5.25
213	68	6.57	9.26	9.37	10.99	12.23	10.37	6.68	5.19
214	77	6.51	8.73	9.44	10.39	10.89	9.98	6.79	5.1
215	81	6.36	8.66	9.08	9.26	10.96	9.62	6.89	5.15
219	62	6.79	9.44	10.45	10.92	12.66	10.63	6.68	5.09
220	65	6.58	9.4	9.66	11.27	12.12	10.11	6.6	5.09
221	69	6.51	8.98	9.62	11.18	11.76	9.93	6.61	5.1
222	72	6.84	8.77	9.19	9.63	10.76	9.67	6.92	5.3
223	82	7.29	8.46	9.04	9.46	10.27	9.81	7.3	5.45
225	52	7.09	10.71	12.5	14.76	13.39	10.19	6.33	4.7
226	56	7.03	9.44	11.5	14.82	13.02	10.74	6.37	4.66
227	60	6.99	9.05	9.81	13.98	12.57	10.79	6.47	4.77
228	63	6.94	8.86	9.81	12.58	12.34	10.51	6.73	4.93
229	66	6.74	8.92	10.12	11.02	12.36	10.15	6.76	5.04
230	68	6.53	8.51	9.26	9.98	12.14	9.99	7.05	5.06
231	75	6.9	8.34	9.06	9.83	11.5	9.89	7.13	5.15
232	84	7.18	8.22	9.1	9.43	10.56	10.09	7.45	5.49
233	59	7.07	9.39	11.4	13.84	12.52	10.81	6.66	4.66
234	57	6.87	9.12	11.42	13.57	12.38	10.54	6.81	4.77
235	61	6.75	8.79	10.38	13.1	11.71	10.48	6.97	4.96
236	65	6.67	8.87	9.83	12.41	11.04	10.43	6.83	5.04
237	67	7.1	8.71	9.29	11.88	10.85	9.93	6.85	5.1
238	71	7.31	8.32	8.93	9.87	11	10.01	7.28	5.15
239	76	7.65	8.25	8.72	9.56	10.99	10.02	7.32	5.35
240	83	7.72	8.21	9.06	9.69	10.49	12.08	7.59	5.55
Average		**6.9**	**9.0**	**10.0**	**11.6**	**11.9**	**10.3**	**6.8**	**5.1**

Table A-7. Bottom water temperature in open area by station from May 2013 through March 2014.

Station	Depth (m)	May '13	Jun '13	Jul '13	Sep '13	Oct '13	Dec '13	Jan '14	Mar '14
273	65	6.85	9.03	11.35	12.25	11.61	10.84	6.99	4.71
274	67	6.73	8.59	10.51	11.77	11.76	10.81	7.14	4.7
275	70	6.6	8.32	10.73	12.43	11.49	10.87	7.31	4.8
276	71	6.71	8.35	11.12	12.4	10.89	10.68	7.16	5.03
277	70	6.77	8.61	10.89	11.23	11.58	10.36	6.98	5.1
278	66	7.04	8.38	10.43	11.23	10.88	10.18	6.99	5.51
279	73	7.24	8.26	9.05	10.91	10.52	10.15	7.05	5.41
286	74	6.65	8.39	9.81	10.68	11.7	11.71	7.55	4.81
287	78	6.43	8.22	9.47	11.05	10.91	11.95	7.49	4.96
288	79	6.3	8.28	9.35	11.17	10.78	11.11	7.4	5.17
289	81	6.9	8.52	9.35	11.06	10.8	11.46	7.08	5.2
290	82	8.81	8.66	9.3	10.28	10.92	12	7.25	6.04
291	84	8.53	8.39	9.48	10.08	10.83	14.11	8.37	5.81
292	85	8.05	9.76	8.82	10.74	10.44	14.69	7.98	5.65
301	34	7.26	9.52	11.3	13.29	12.97	10.91	6.69	4.73
302	35	6.93	9.45	10.42	12.9	12.19	11.08	7.07	4.77
303	35	7.27	9.06	11.02	13.24	12.29	11.32	6.98	4.72
304	37	7.1	9.21	10.46	12.59	12.25	11.06	7.21	4.71
305	40	6.79	8.54	9.99	11.1	12.08	11	7.26	4.72
306	37	7.18	9.18	9.86	11.77	12.4	11.45	8.06	4.67
307	36	7.27	9.1	9.79	11.7	12.15	11.4	7.85	4.67
308	38	7.11	8.72	9.93	11.3	11.62	11.64	7.69	4.75
309	42	6.79	8.65	9.53	10.74	11.66	11.31	8.14	5.02
310	46	6.49	8.48	9.41	10.47	11.42	14.39	8.67	5.11
312	38	7.05	8.21	10.32	10.87	13.25	11.99	8.49	4.46
313	42	6.88	8.09	9.9	10.59	12.48	12.02	8.98	4.45
314	44	6.89	8.16	9.82	10.74	12.41	12.04	9.27	4.52
315	45	6.84	8.21	9.64	10.51	11.71	11.98	8.95	5.03
316	43	6.74	8.68	9.45	10.73	11.58	11.95	8.61	5.11
317	42	6.83	8.36	9.57	10.86	11.65	11.86	8.43	5.25
Average		**7.0**	**8.6**	**10.0**	**11.4**	**11.6**	**11.6**	**7.7**	**5.0**

Table A-8. Male yellowtail flounder maturity results. I-immature, D-developing, R-ripe, U- ripe and running, S- spent, T- resting.

	Month	I	D	R	U	S	T	Total
CAI	May	0	0	16	2	0	0	18
	Jun	0	0	10	2	5	2	19
	Jul	1	0	2	0	0	3	6
	Sep	1	0	0	0	0	22	23
	Oct	0	0	0	0	0	1	1
	Dec	0	3	1	0	0	0	4
	Jan	0	0	0	0	0	0	0
	Mar	0	0	0	0	0	0	0
CAII	May	0	0	30	0	2	0	32
	Jun	0	0	2	0	6	4	12
	Jul	0	0	3	0	7	17	27
	Sep	0	0	0	0	3	53	56
	Oct	0	2	0	0	0	75	77
	Dec	0	28	0	0	0	2	30
	Jan	0	21	20	0	0	3	44
	Mar	0	14	27	0	0	0	41
Open Area	May	0	0	11	0	0	0	11
	Jun	0	0	0	0	2	0	2
	Jul	0	0	0	0	0	1	1
	Sep	1	1	0	0	0	27	29
	Oct	0	3	0	0	0	32	35
	Dec	0	14	0	0	0	0	14
	Jan	0	0	1	0	0	0	1
	Mar	0	0	2	0	0	0	2

Table A-9. Female yellowtail flounder maturity results for the open area, other results are presented in the text. I-immature, D-developing, R-ripe, U- ripe and running, S- spent, T- resting.

	Month	I	D	R	U	S	T	Total
Open Area	May	0	2	90	0	35	0	127
	Jun	0	0	9	0	70	13	92
	Jul	0	12	0	0	4	22	38
	Sep	2	1	0	0	3	45	51
	Oct	0	26	0	0	0	58	84
	Dec	0	66	4	0	1	1	72
	Jan	0	20	15	0	0	1	36
	Mar	0	0	8	0	0	0	8

Table A-10. Male winter flounder maturity results. I-immature, D-developing, R-ripe, U- ripe and running, S- spent, T- resting.

	Month	I	D	R	U	S	T	Total
CAI	May	0	1	1	1	1	0	4
	Jun	0	0	0	0	0	25	25
	Jul	0	0	0	0	9	44	53
	Sep	0	0	0	0	0	42	42
	Oct	0	8	0	0	0	9	17
	Dec	0	24	21	1	0	2	48
	Jan	0	2	6	0	0	0	8
	Mar	0	0	4	0	0	0	4
CAII	May	0	0	0	1	1	0	2
	Jun	0	0	0	0	0	0	0
	Jul	0	0	0	0	2	0	2
	Sep	0	0	0	0	0	11	11
	Oct	0	8	0	0	0	1	9
	Dec	0	2	4	0	0	0	6
	Jan	0	0	5	0	0	0	5
	Mar	0	0	2	4	0	0	6
Open Area	May	0	0	0	0	0	0	0
	Jun	0	0	0	0	0	0	0
	Jul	0	0	0	0	0	3	3
	Sep	0	0	0	0	0	11	11
	Oct	0	2	0	0	0	1	3
	Dec	0	0	3	0	0	0	3
	Jan	0	0	2	0	0	0	2
	Mar	0	0	0	0	0	0	0

Table A-11. Female Winter flounder maturity results for the open area, other results are presented in the text. I-immature, D-developing, R-ripe, U- ripe and running, S- spent, T- resting.

	Month	I	D	R	U	S	T	Total
Open Area	May	0	0	0	0	6	0	6
	Jun	0	0	0	0	1	10	11
	Jul	0	0	0	0	0	1	1
	Sep	0	0	1	0	0	11	12
	Oct	0	15	0	0	0	0	15
	Dec	0	8	9	0	0	0	17
	Jan	0	0	10	0	0	0	10
	Mar	0	0	0	0	0	0	0

Table A-12. ANCOVA summary statistics for gray meat section comparing shell height meat weight relationship for white meat vs discolored scallops for CAI and CAII

CAI						
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
SH	1	9.715	9.715	1571.611	<2e-16	***
color	1	2.097	2.097	339.3	<2e-16	***
SH:color	1	0.001	0.001	0.135	0.713	
Residuals	721	4.457	0.006			
CAII						
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
SH	1	10.238	10.238	1526.179	<2e-16	***
color	1	0.621	0.621	92.515	<2e-16	***
SH:color	1	0.021	0.021	3.094	0.079	.
Residuals	656	4.4	0.007			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table A-13. ANOVA summary statistics for gray meat section comparing shell height meat weight relationship for white meat vs discolored scallops for CAI and CAII.

CAI						
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
SH	1	9.715	9.715	1573.5	<2e-16	***
color	1	2.097	2.097	339.7	<2e-16	***
Residuals	722	4.458	0.006			
CAII						
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
SH	1	10.238	10.238	1521.33	<2e-16	***
color	1	0.621	0.621	92.22	<2e-16	***
Residuals	657	4.421	0.007			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table A-14. Comparison of ANCOVA and ANOVA models for gray meat section comparing shell height meat weight relationship for white meat vs discolored scallops for CAI and CAII

CAI						
	Res.Df	RSS	Df	Sum of Sq	F	Pr(>F)
1	721	4.457				
2	722	4.4579	-1	-0.00084	0.1351	0.7133
CAII						
	Res.Df	RSS	Df	Sum of Sq	F	Pr(>F)
1	656	4.4004				
2	657	4.4212	-1	-0.02076	3.0942	0.07904

Appendix B: Seasonal distribution maps of species caught during the 2013 seasonal bycatch survey. Grids surrounding the stations are for visual purposes only. Total catch for both dredges combined were plotted using the fixed survey point.

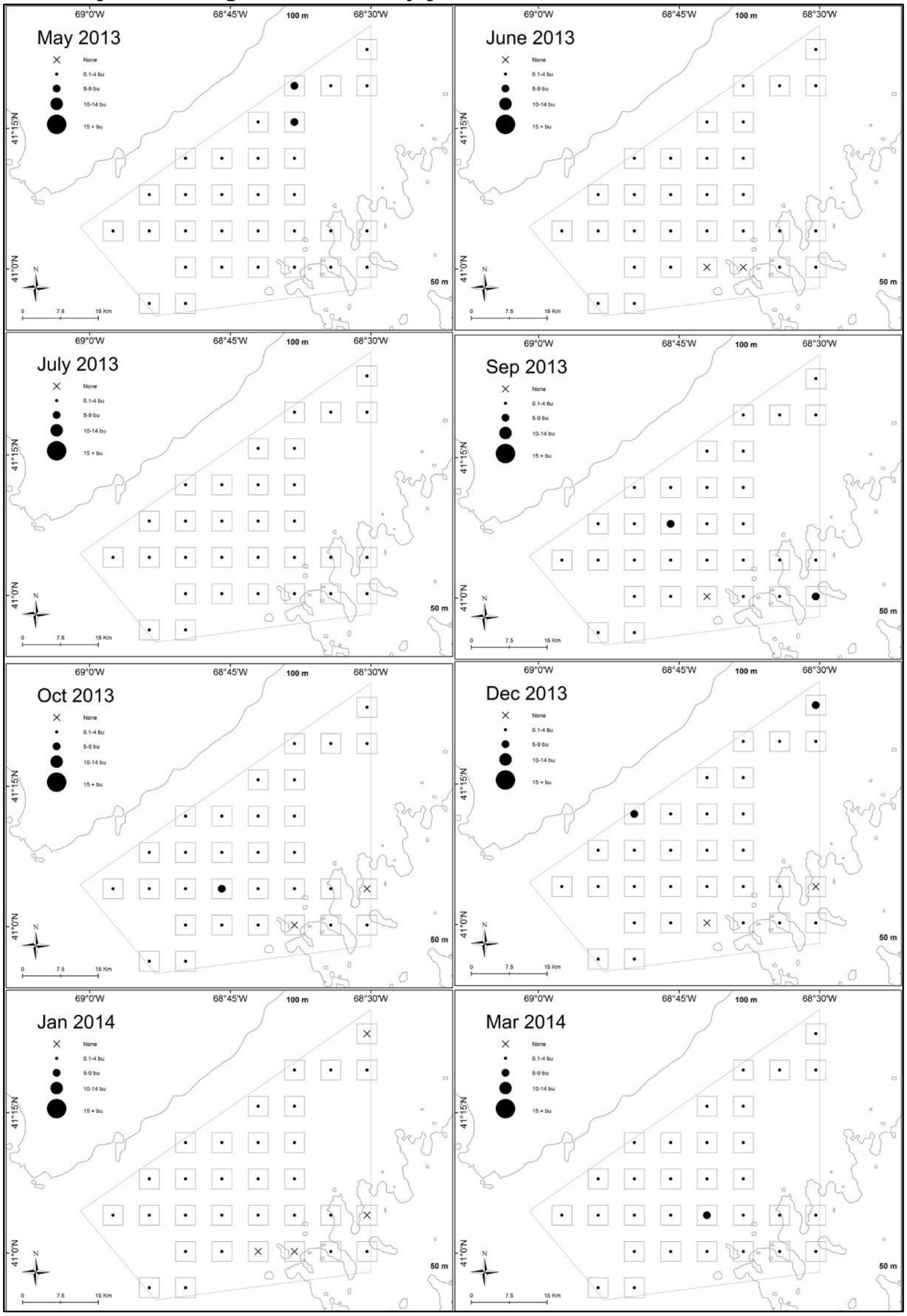


Figure B-1. Seasonal distribution of scallops in CAI during the 2013 bycatch survey. The catch size (bushels) is represented by the size of the marker, locations with X represent no catch.

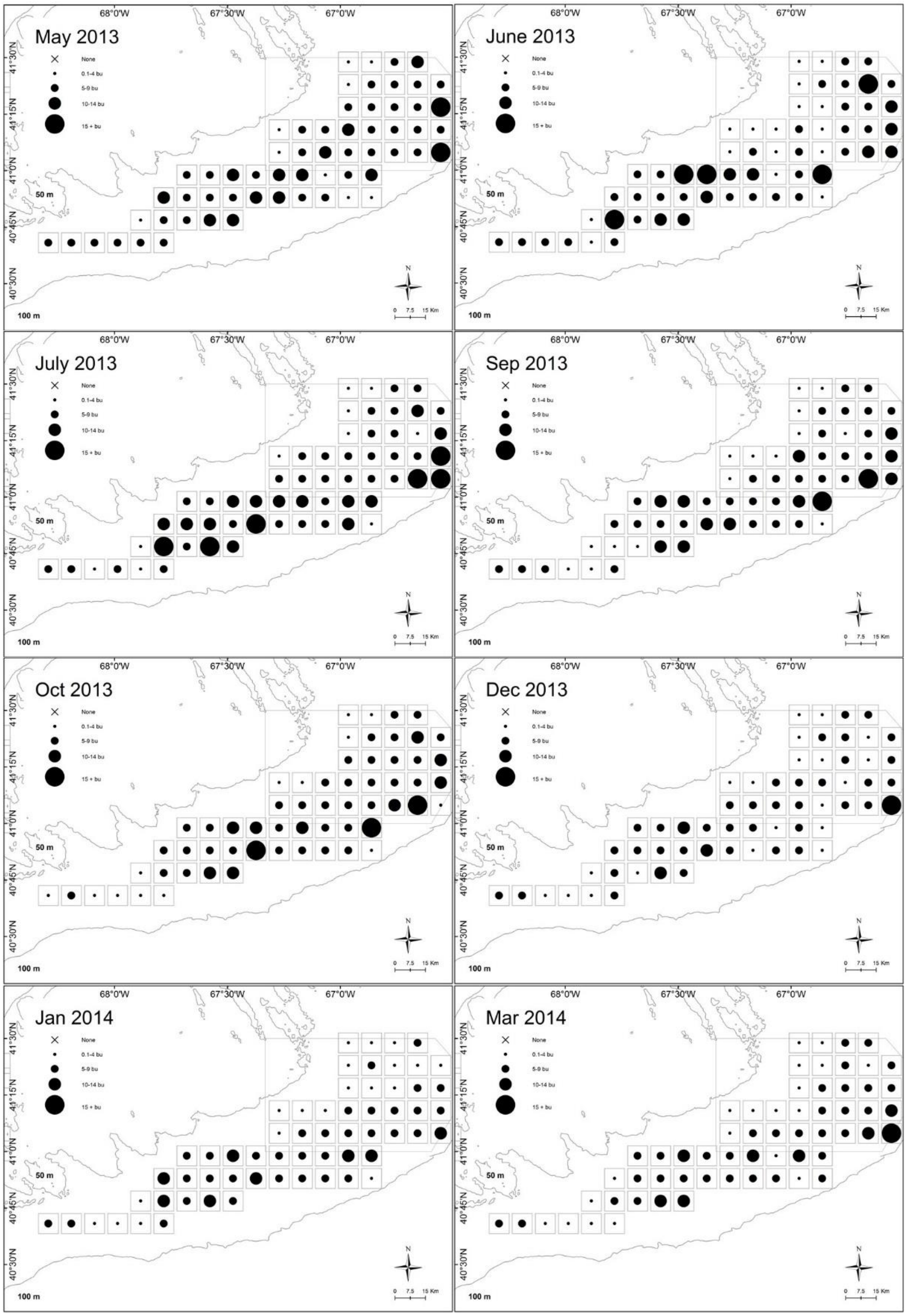


Figure B-2. Seasonal distribution of scallops in CAII and open area during the 2013 bycatch survey. The catch size (bushels) is represented by the size of the marker, locations with X represent no catch.

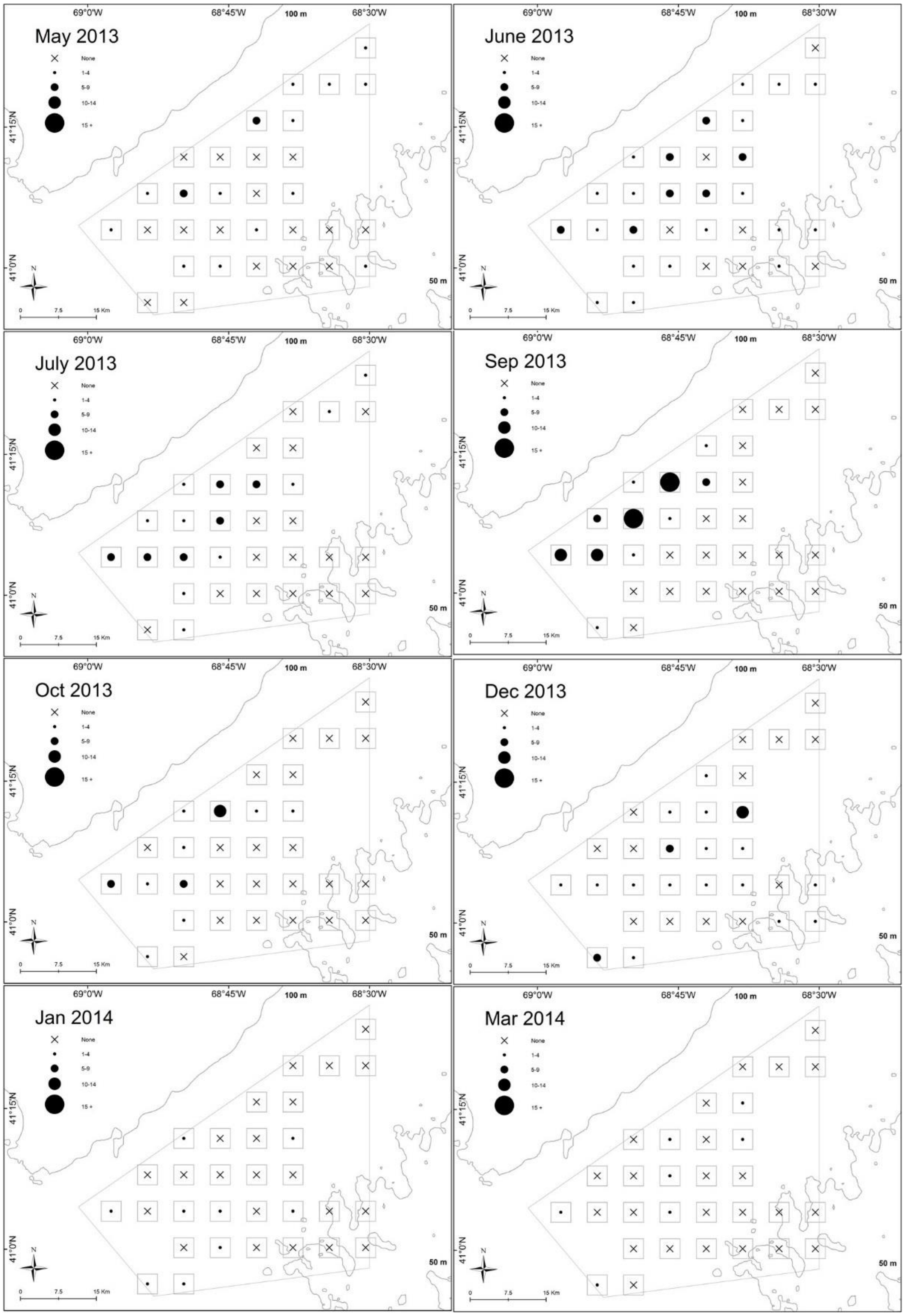


Figure B-3. Seasonal distribution of yellowtail flounder in CAI during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

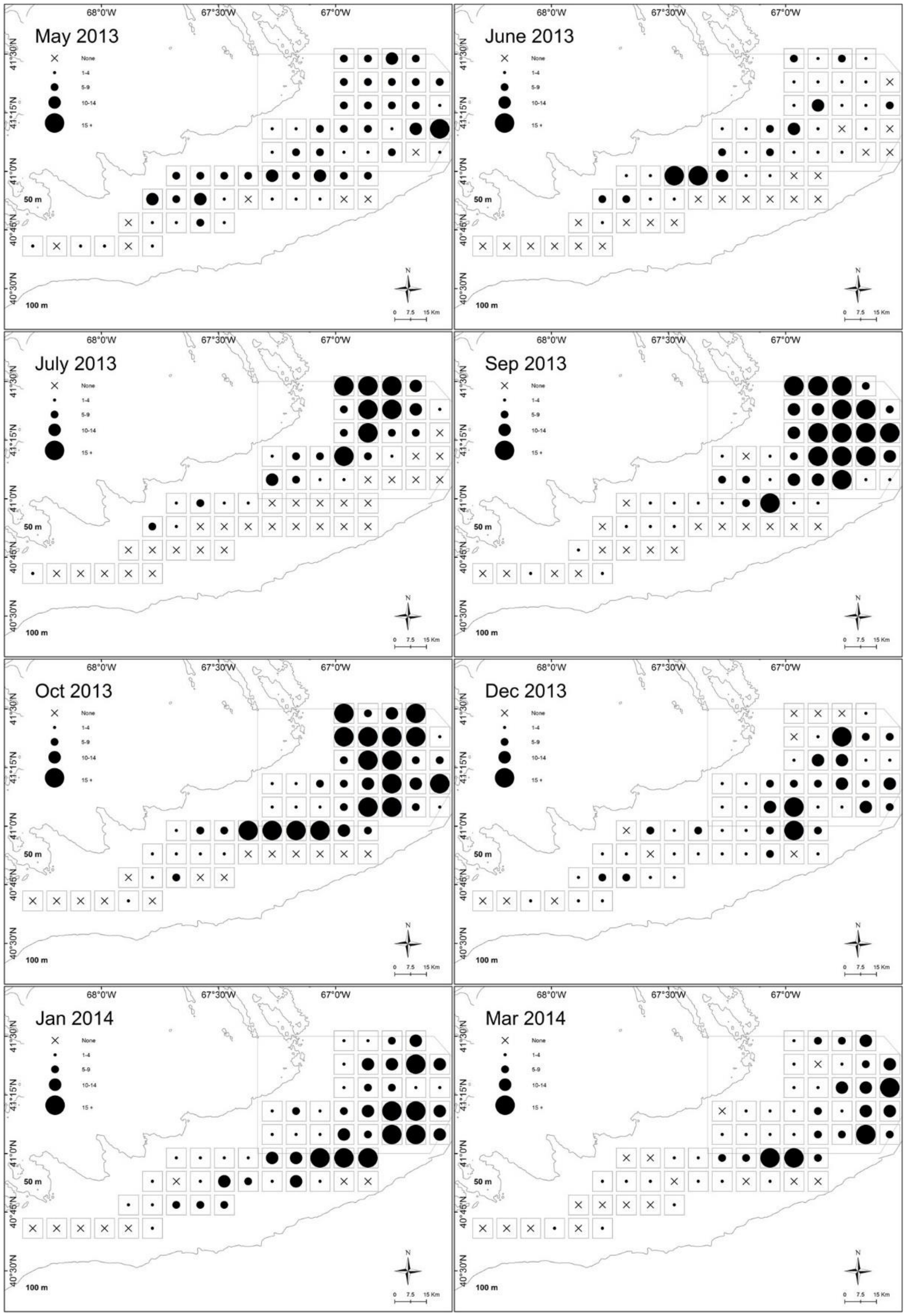


Figure B-4. Seasonal distribution of yellowtail flounder in CAII and open area during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

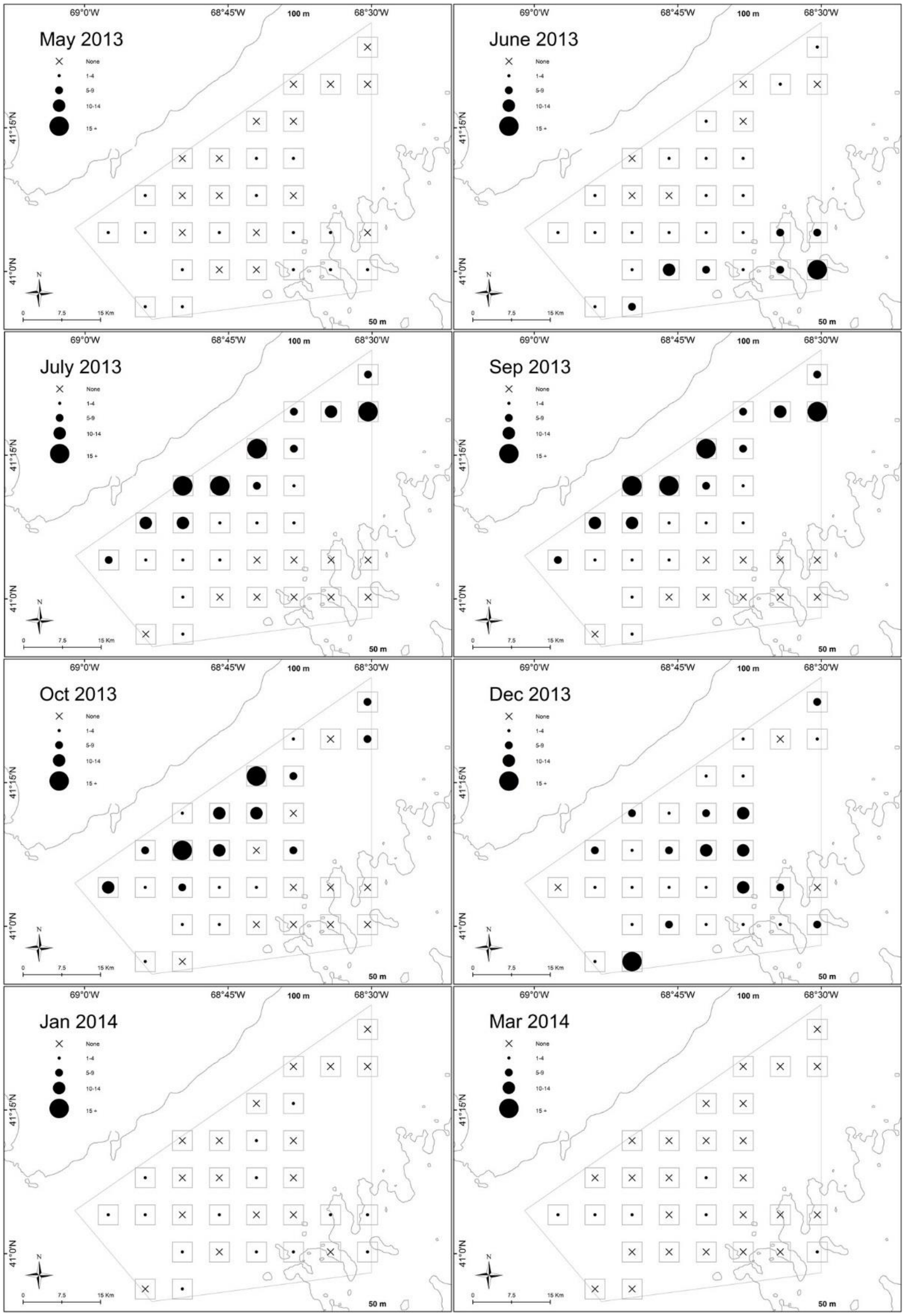


Figure B-5. Seasonal distribution of winter flounder in CAI during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

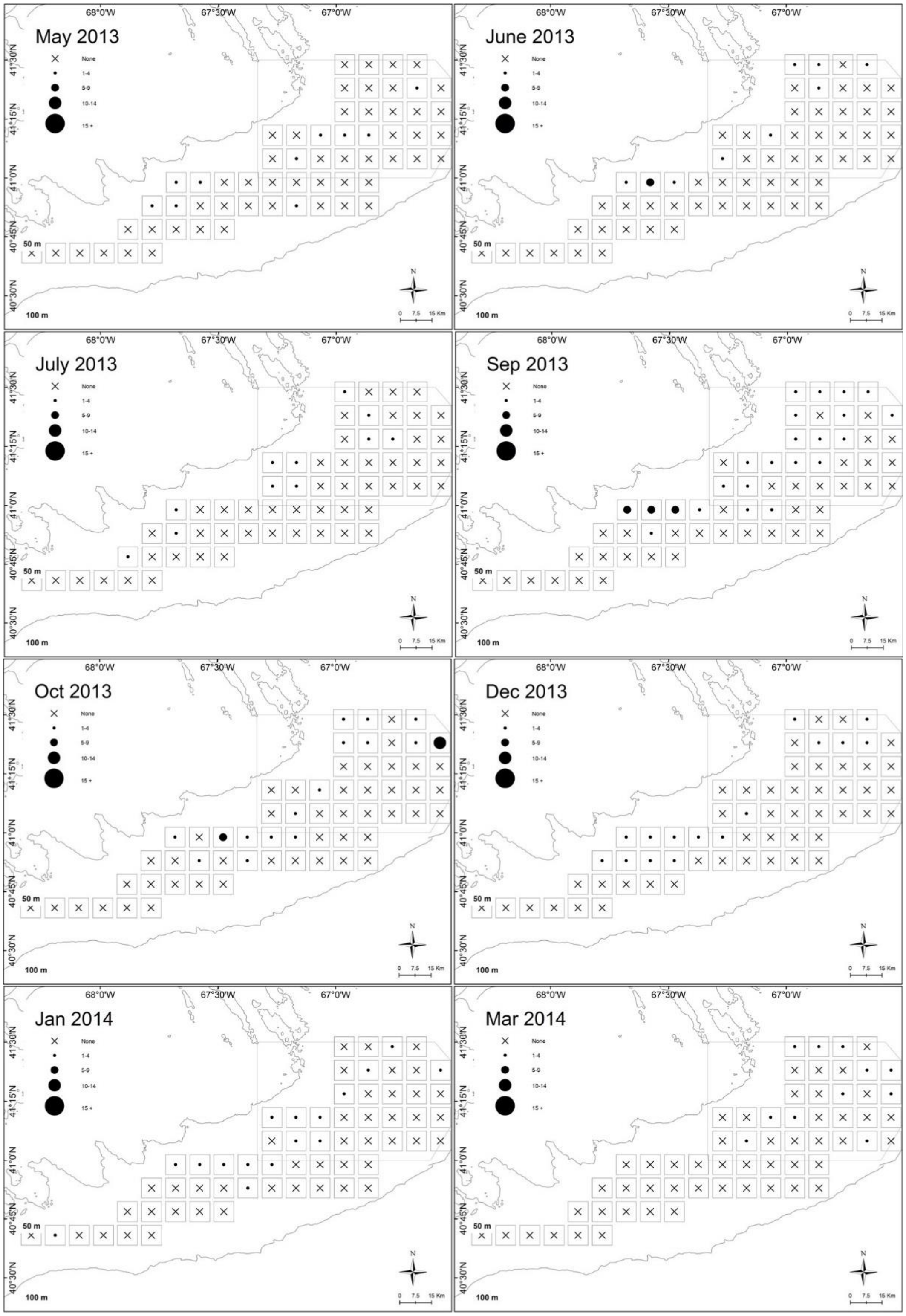


Figure B-6. Seasonal distribution of winter flounder in CAII and open area during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

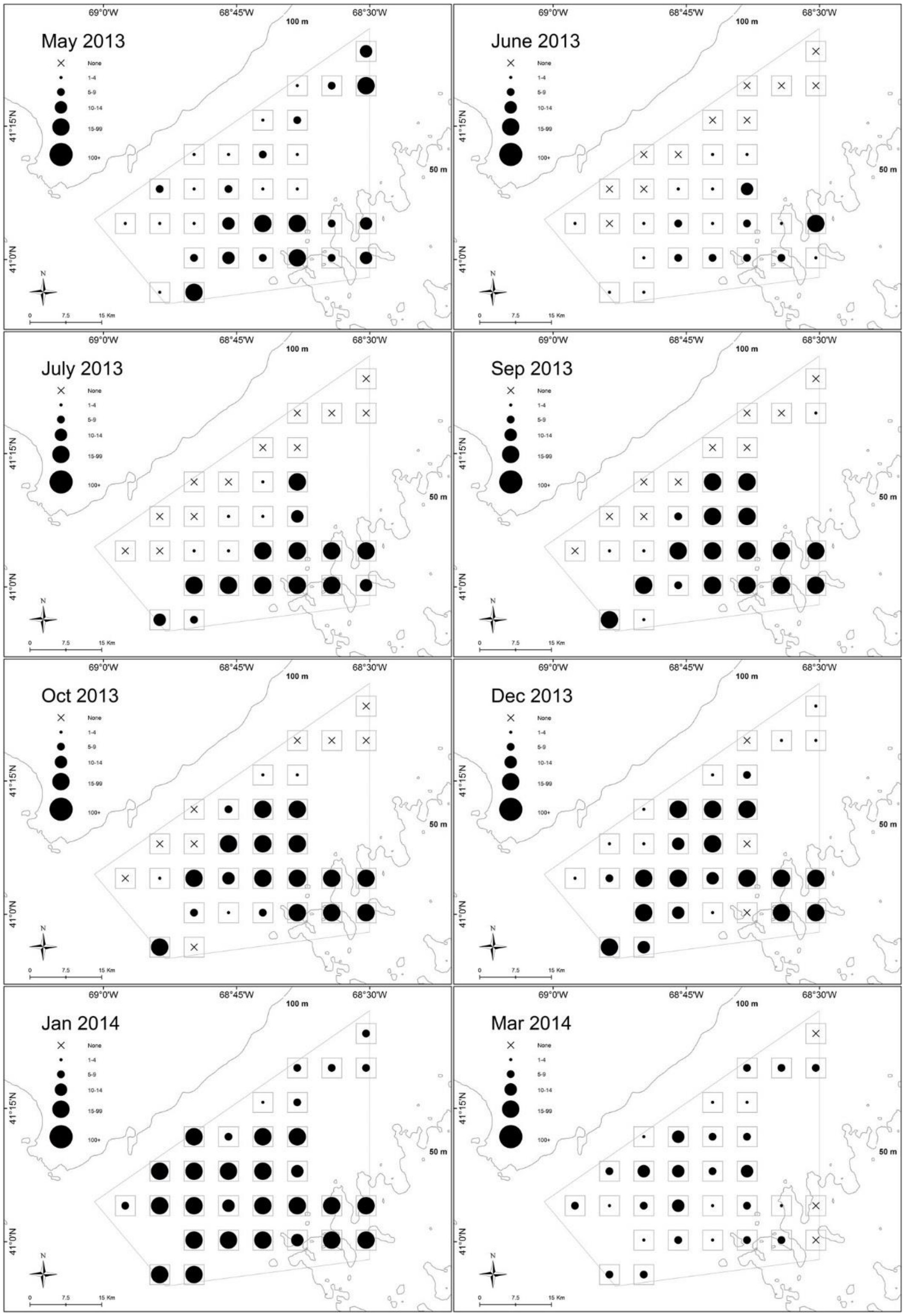


Figure B-7. Seasonal distribution of windowpane flounder in CAI during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

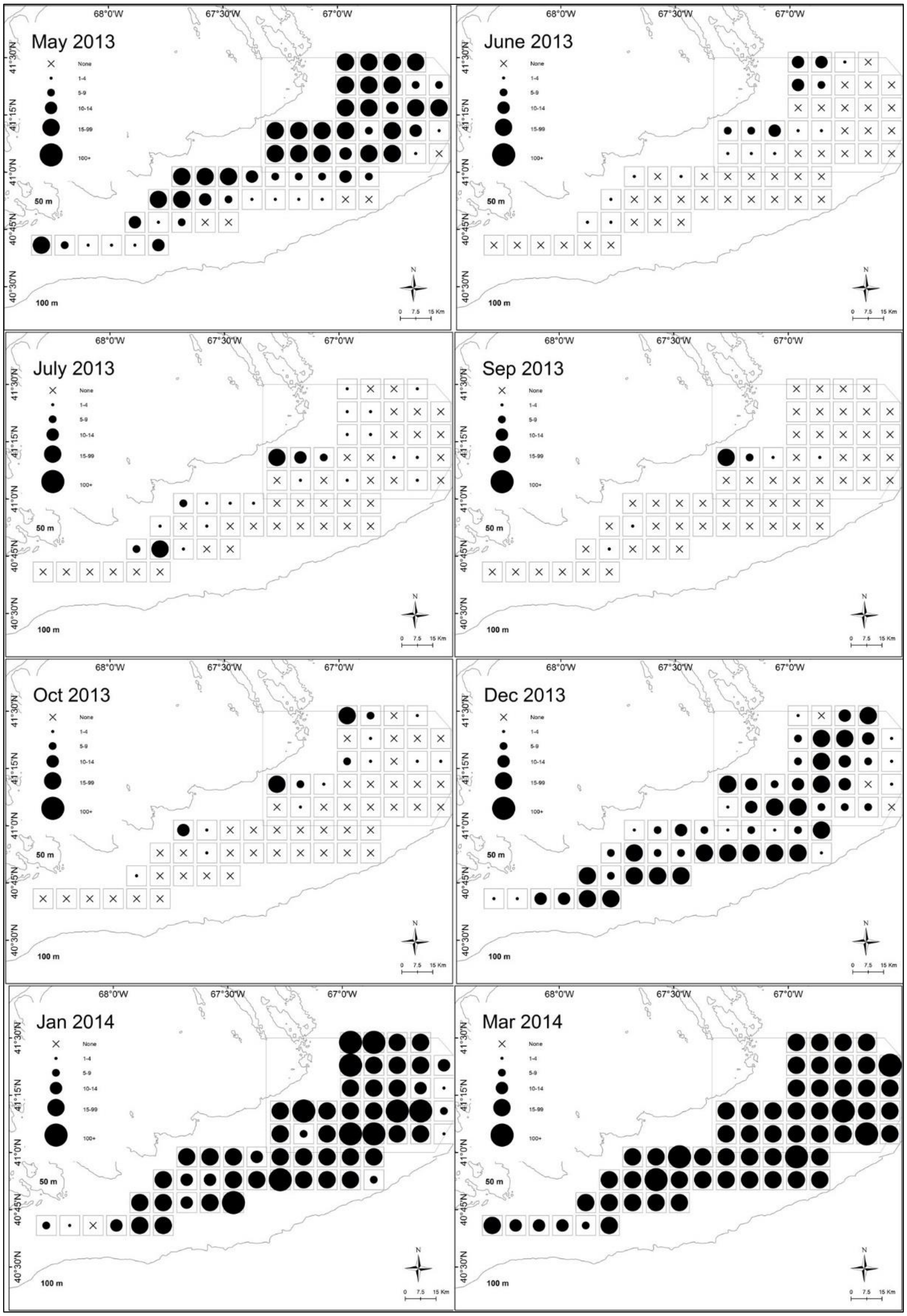


Figure B-8. Seasonal distribution of windowpame flounder in CAII and open area during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

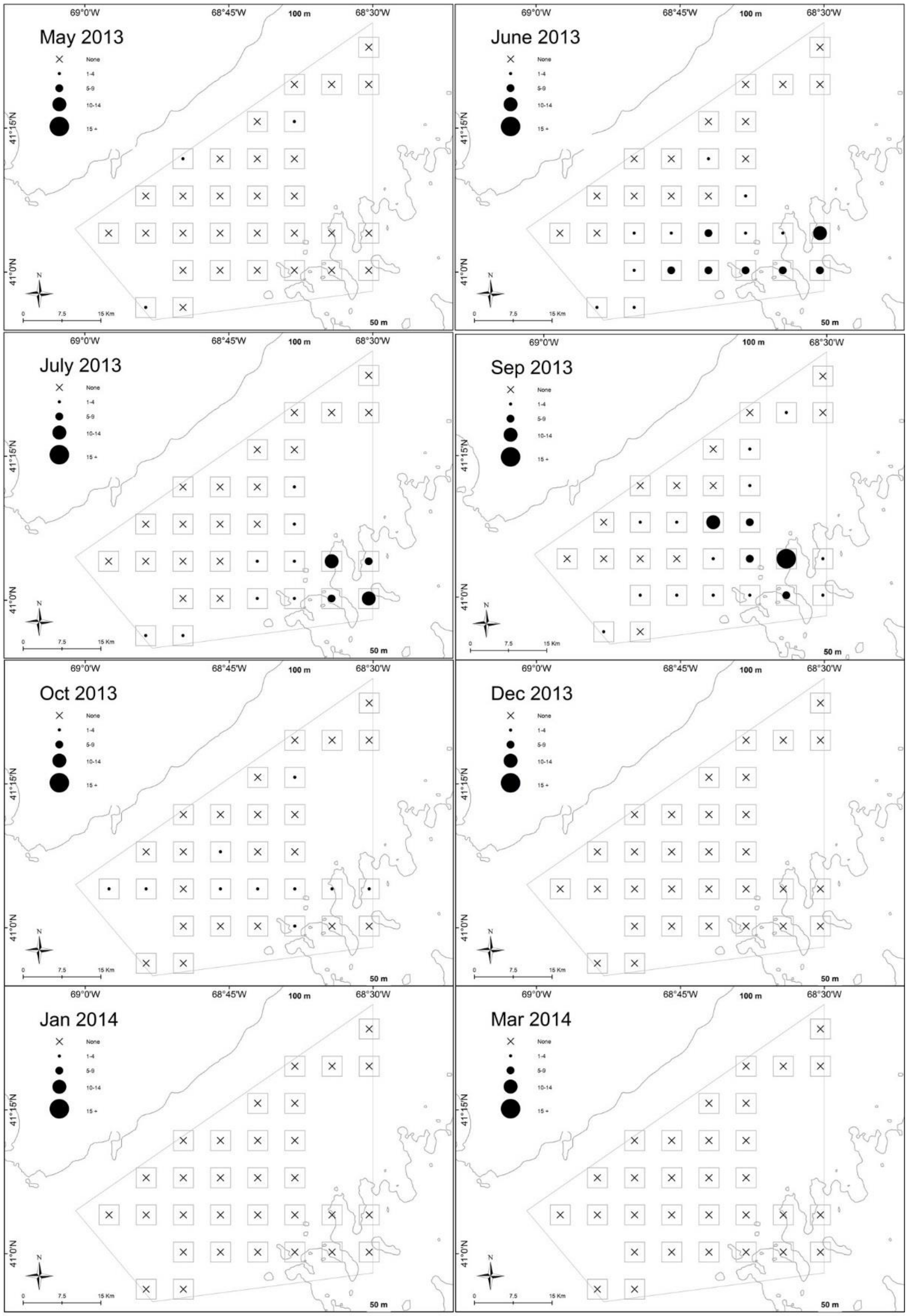


Figure B-9. Seasonal distribution of summer flounder in CAI during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

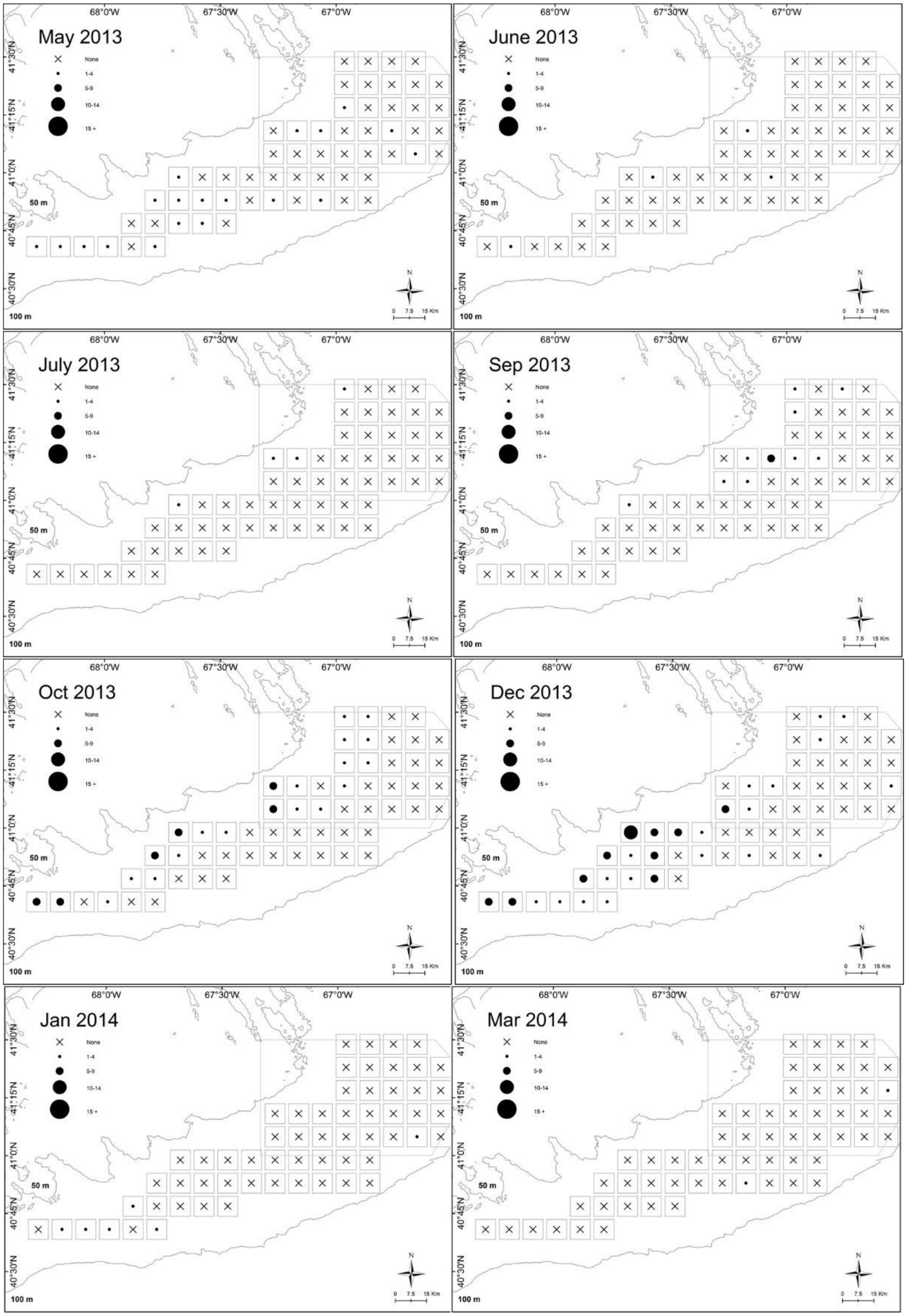


Figure B-10. Seasonal distribution of summer flounder in CAII and open area during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

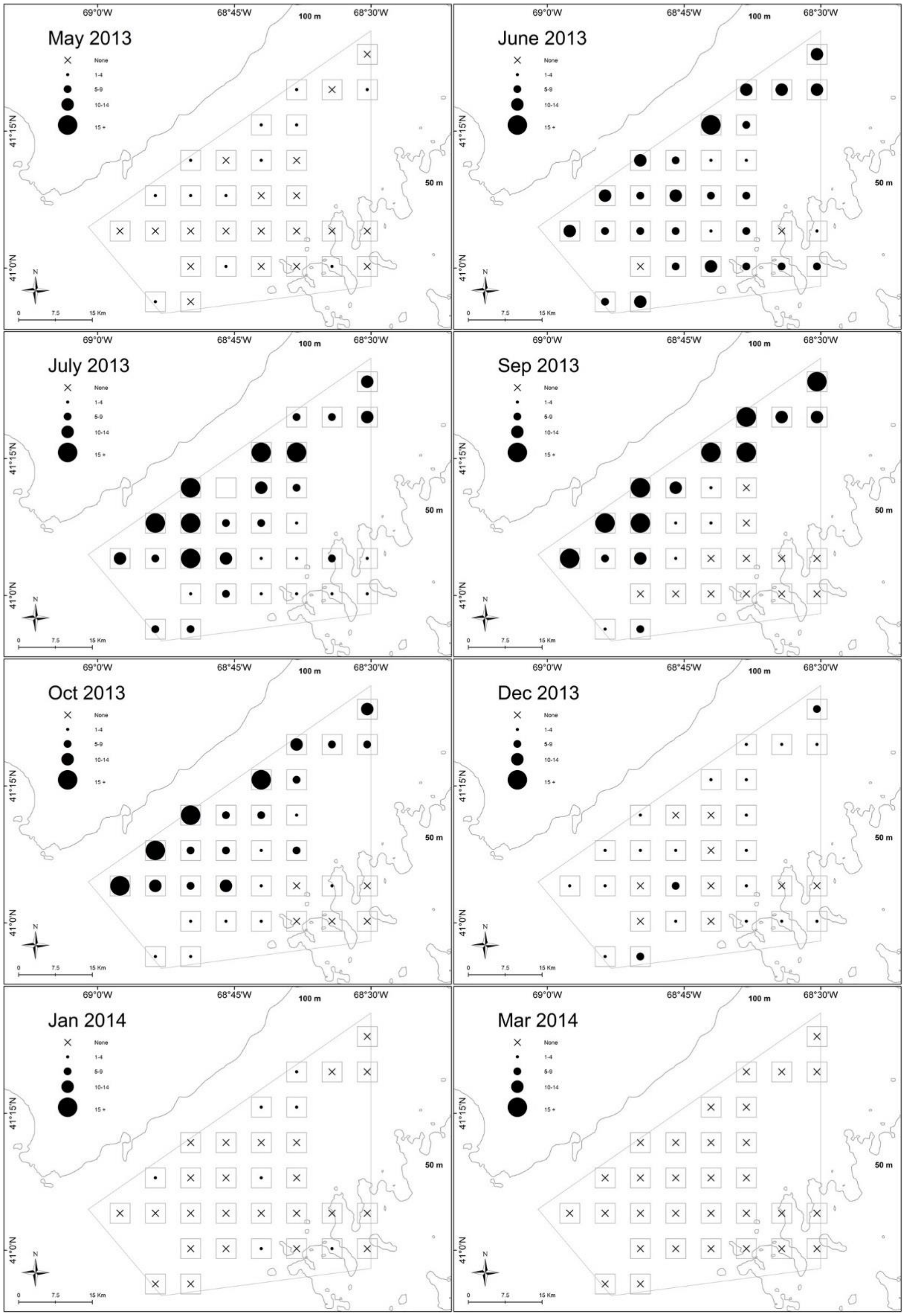


Figure B-11. Seasonal distribution of monkfish in CAI during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

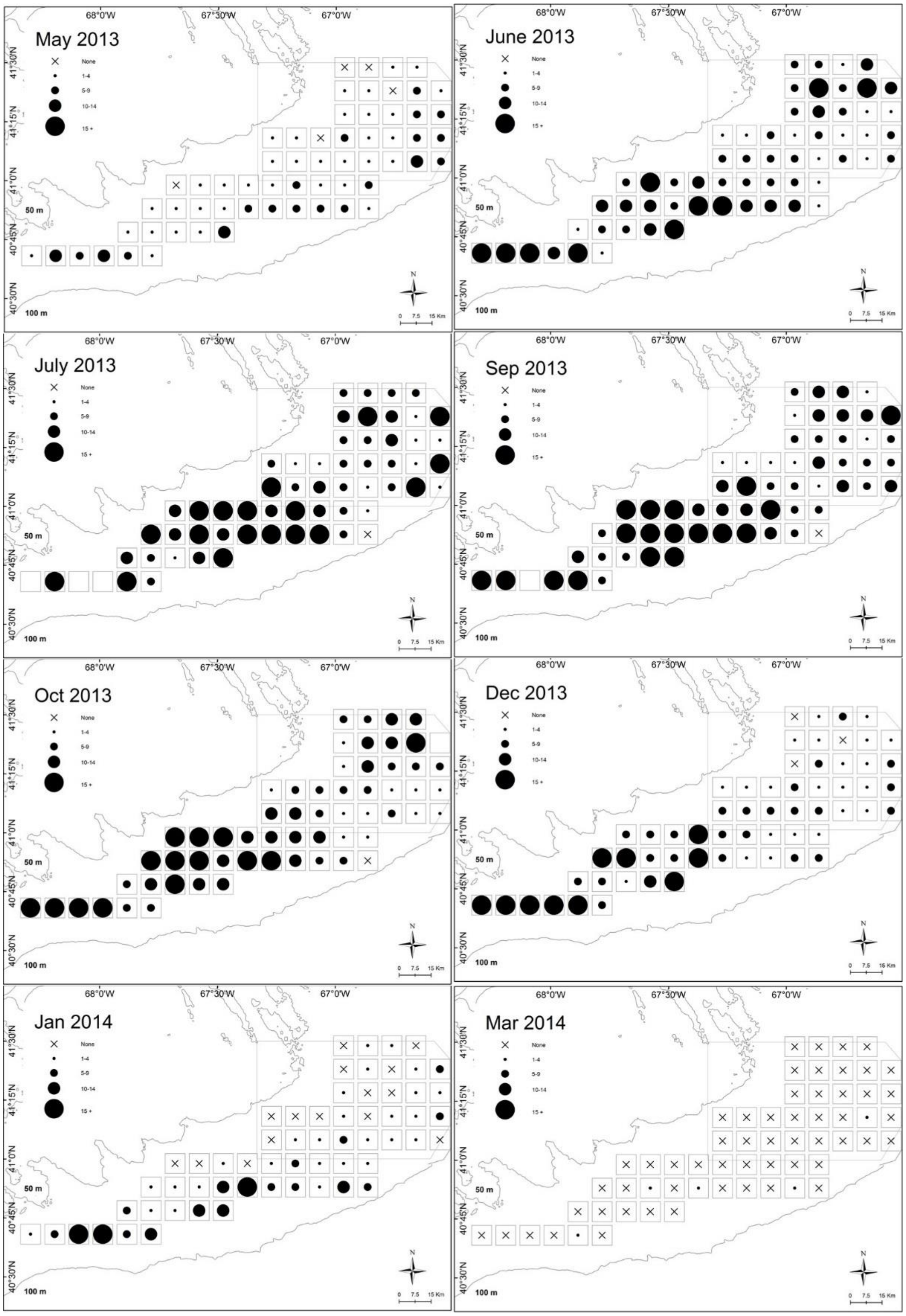


Figure B-12. Seasonal distribution of monkfish in CAII and open area during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

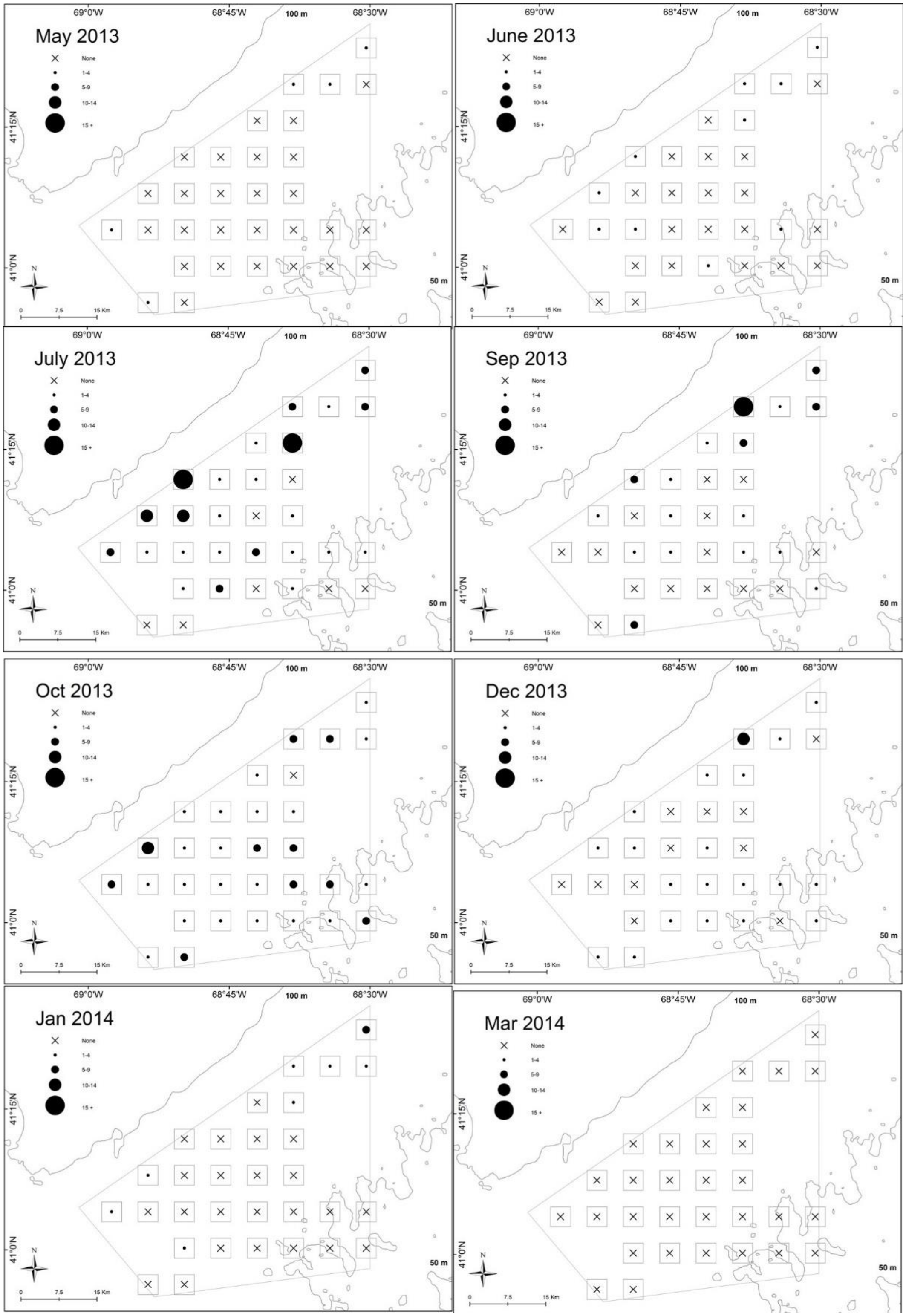


Figure B-13. Seasonal distribution of barndoor skate in CAI during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

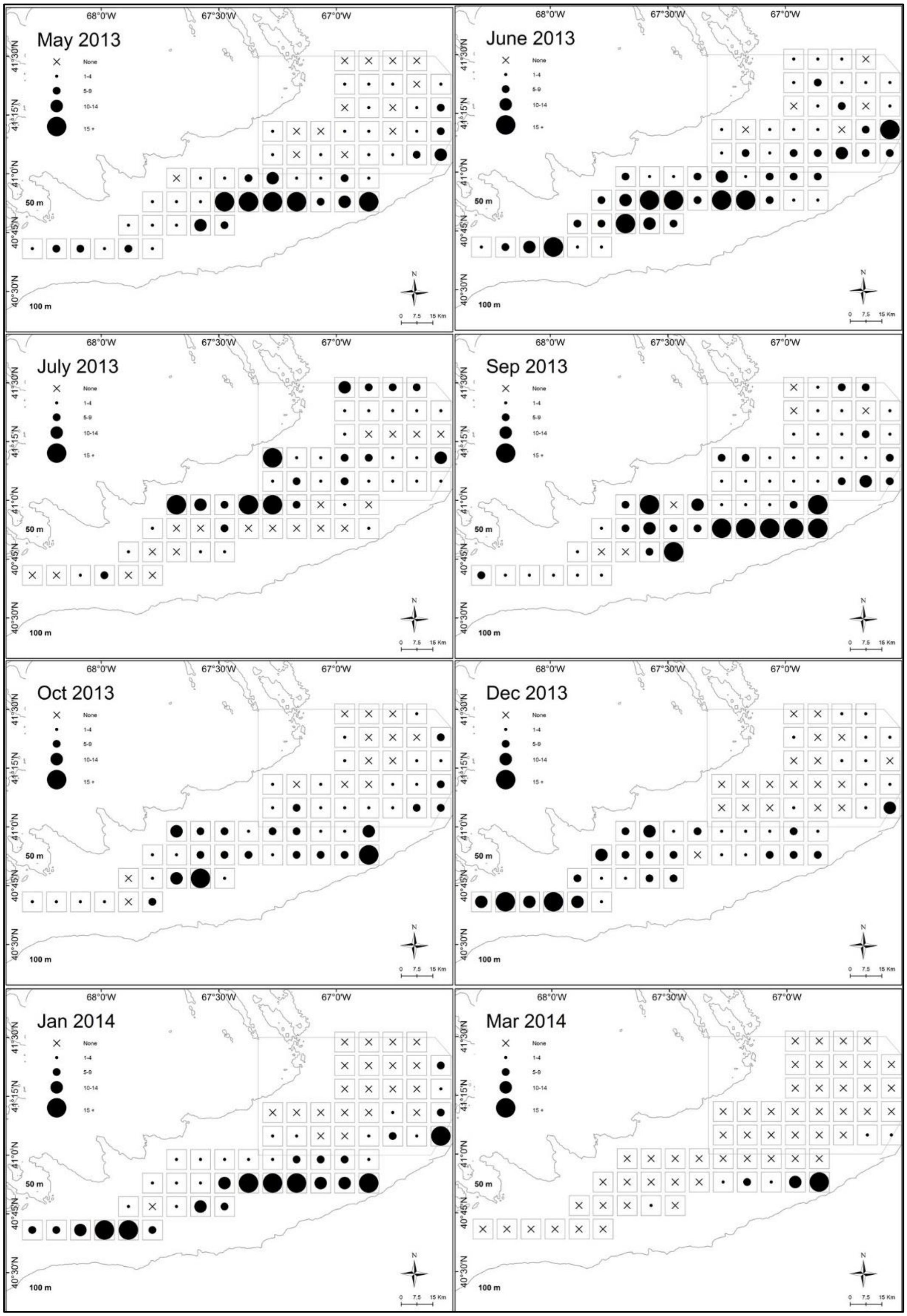


Figure B-14. Seasonal distribution of barndoor skate in CAI during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

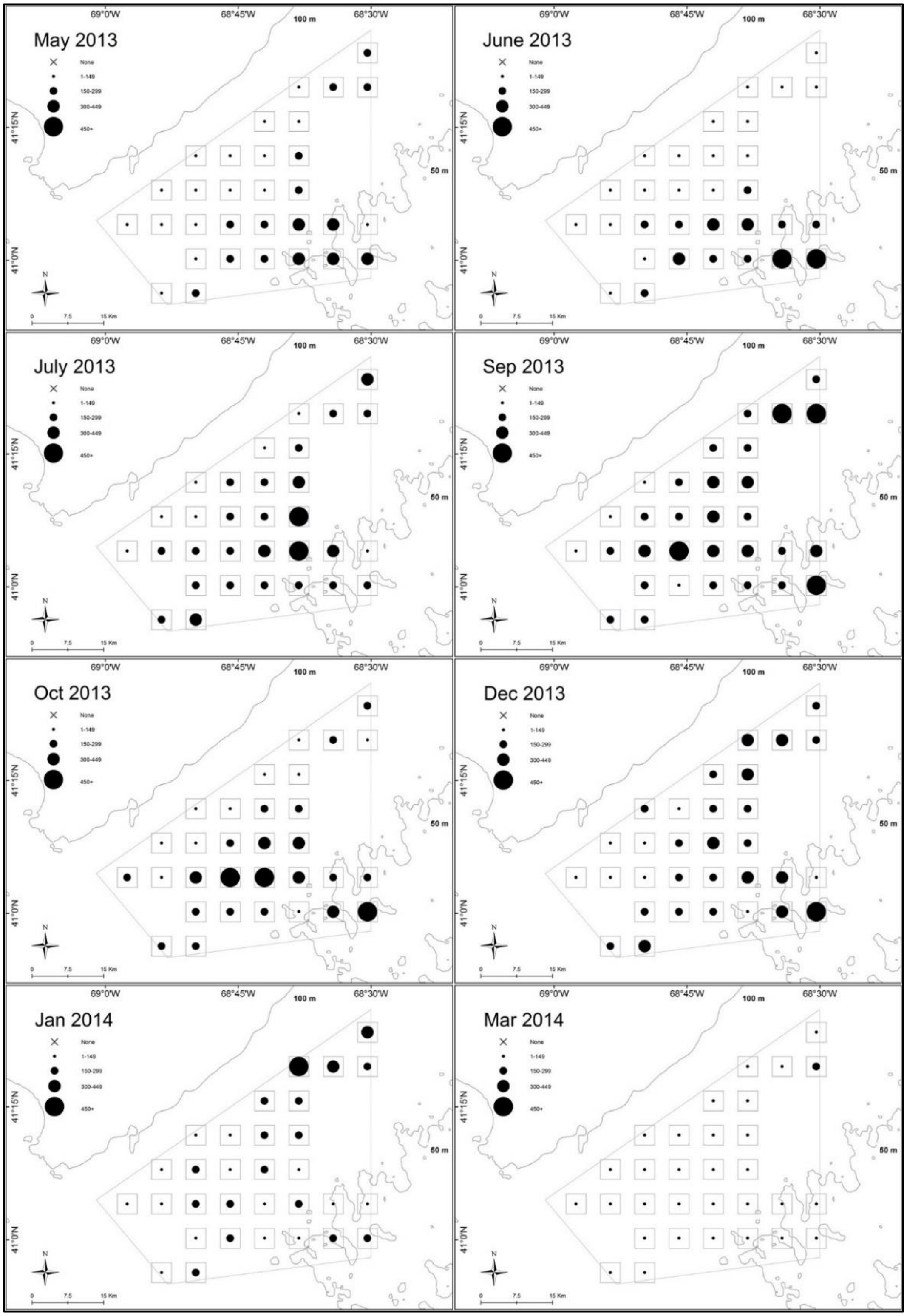


Figure B-15. Seasonal distribution of skate in CAI during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

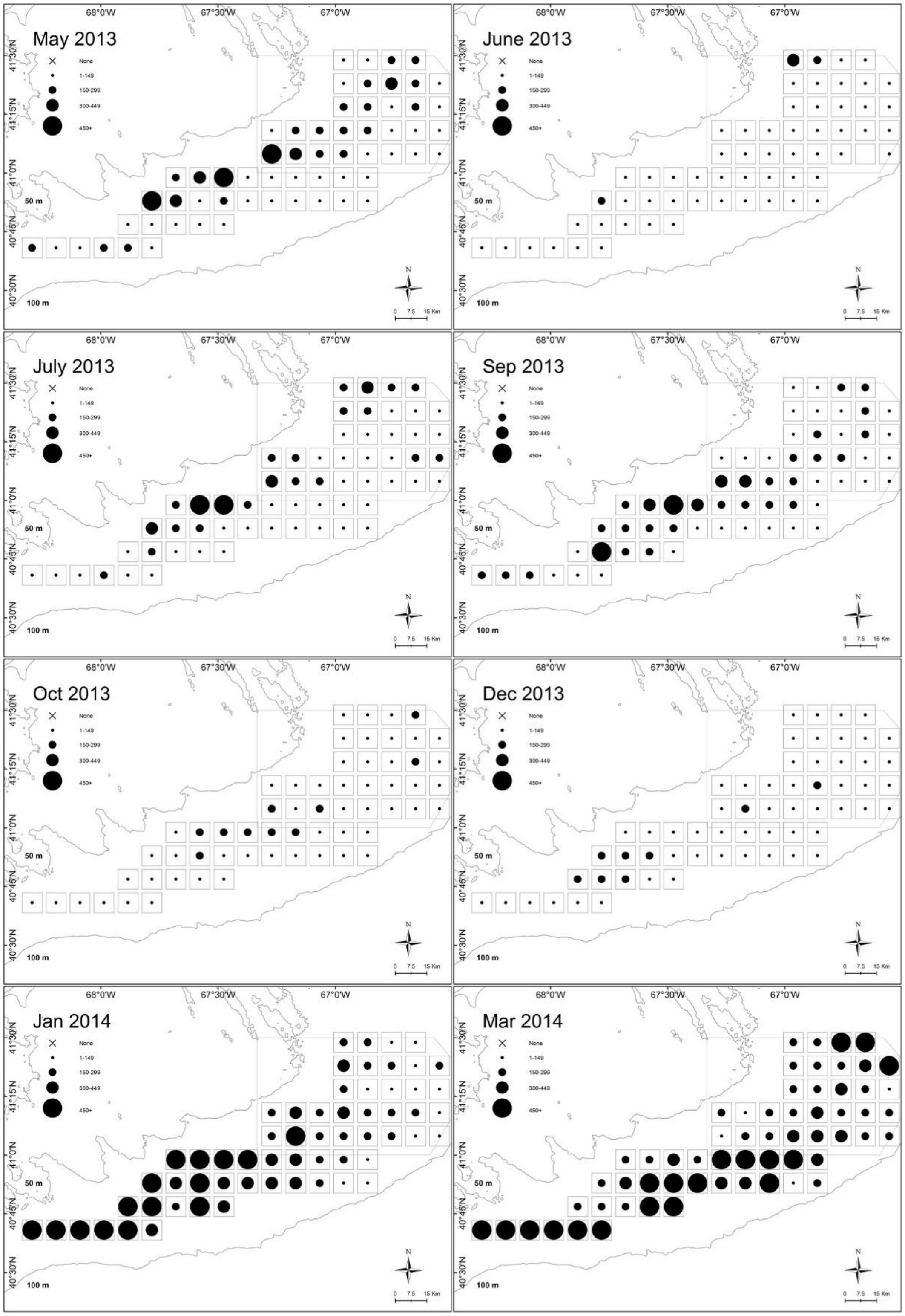


Figure B-16. Seasonal distribution of skate in CAII and open area during the 2013 bycatch survey. The catch size (numbers) is represented by the size of the marker, locations with X represent no catch.

Appendix C: 2011-2013 Bycatch Survey Results

Table C-1 Dates for all trips for the seasonal bycatch survey from 2010 until 2014. Used to compare catch between years

2011 Seasonal Bycatch Survey Trips (NA11NMF4540027):	
F/V Arcturus	March 9 – 15, 2011
F/V Celtic	April 14 – 20, 2011
F/V Westport	May 11 – 17, 2011
F/V Liberty	June 1 – 7, 2011
F/V Endeavor	July 6 – 12, 2011
F/V Regulus	Aug 15 – 21, 2011
F/V Resolution	Sept 10 – 16, 2011
F/V Ranger	Oct. 4 – 10, 2011
F/V Horizon	Nov 29 - Dec 5, 2011
F/V Wisdom	Jan 4 – 10, 2012
F/V Venture	Feb 16 – 22, 2012
F/V Regulus	March 10 – 16, 2012
F/V Endeavor	April 10 – 16, 2012
2012 Seasonal Bycatch Survey Trips (NA12NMF4540034):	
F/V Zibet	May 04 – 11, 2012
F/V Kayla Rose	June 20 – 26, 2012
F/V Anticipation	August 06 – 14, 2012
F/V Liberty	September 25 – October 01, 2012
F/V Horizon	November 3 – 12, 2012 (Nov. 3-7; Nov. 9-12)
F/V Thor	December 04 – 16, 2012 (Dec. 04-07; Dec. 11-16)
F/V Polaris	January 28 – February 03, 2013
F/V Vanquish	March 15 – 22, 2013 (Mar. 15-20; Mar. 21-23)
2013 Seasonal Bycatch Survey Trips (NA13NMF4540011):	
F/V Endeavor	April 27 – May 4, 2013
F/V Zibet	June 12 – 18, 2013
F/V Venture	July 26 – June 2, 2013
F/V Atlantic	September 9 – 14, 2013
F/V Regulus	October 26 – November 2, 2013
F/V Vanquish	December 10 – 18, 2013
F/V Horizon	January 15 – 22, 2014
F/V Liberty	March 8 – 13, 2014

Table C-2. List of all stations continuously sampled for every survey trip from 2010 until 2014. For a total of 11 stations in closed area I (CAI) and 23 in closed area II (CAII). These stations were used to compare catch between years.

CAI		CAII			
101	126	205	220	229	236
111	127	206	221	230	237
117	135	212	222	231	238
123	136	213	226	233	239
124	138	214	227	234	240
125		219	228	235	

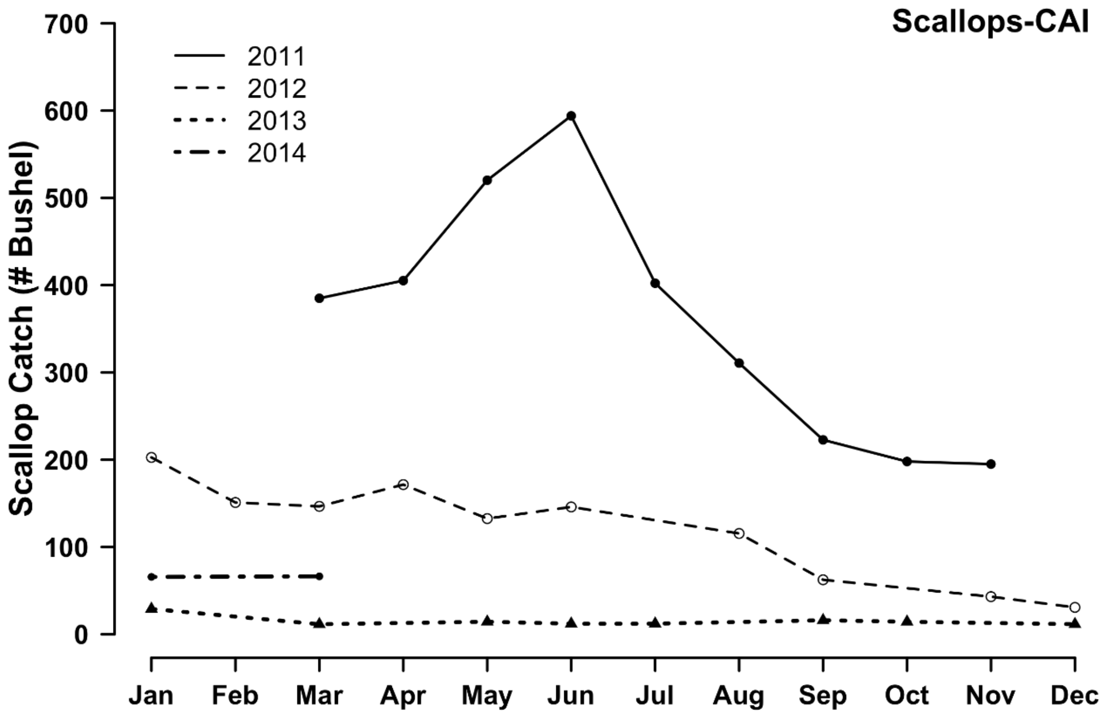


Figure C-1. Scallop catch (# bushels) in the standardized TDD from March 2011 through March 2014 at 11 stations consistently sampled in Closed Area I (CAI).

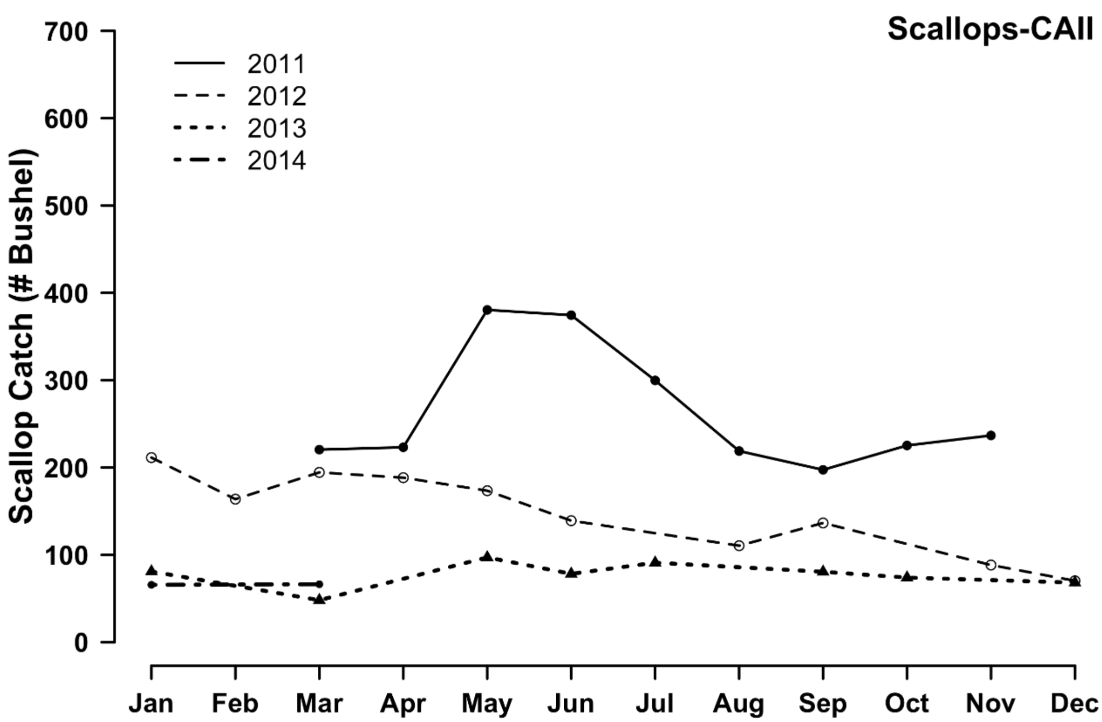


Figure C-2. Scallop catch (# bushels) in the standardized TDD from March 2011 through March 2014 at 23 stations consistently sampled in Closed Area II (CAII).

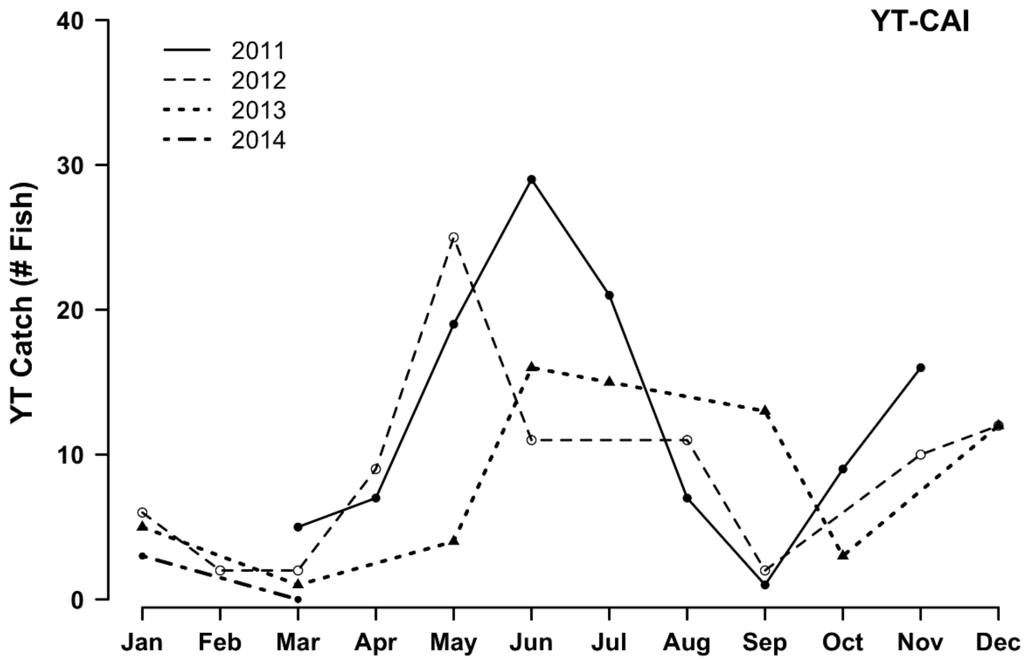


Figure C-3. Yellowtail catch (# fish) in the standardized TDD from March 2011 through March 2014 at 11 stations consistently sampled in Closed Area I (CAI).

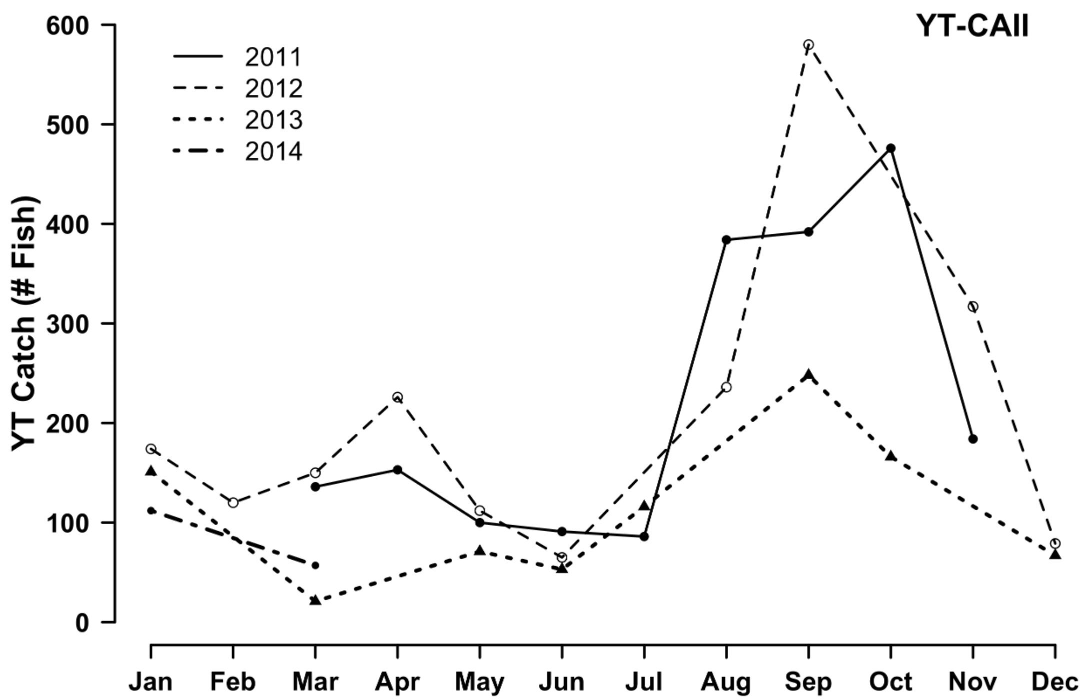


Figure C-4. Yellowtail catch (# fish) in the standardized TDD from March 2011 through March 2014 at 23 stations consistently sampled in Closed Area II (CAII).

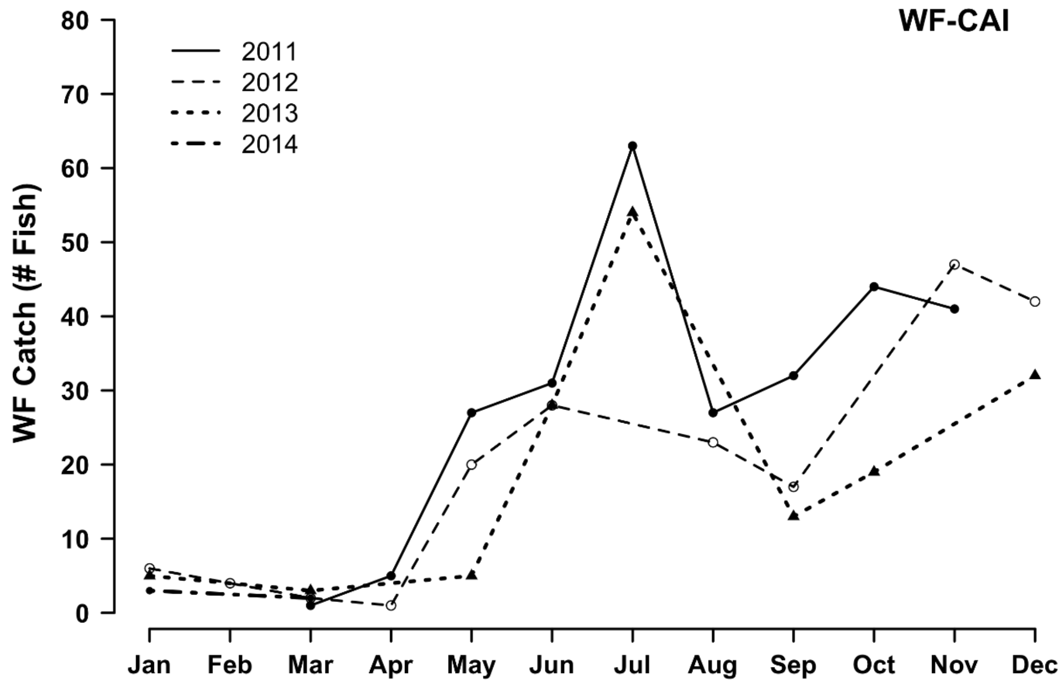


Figure C-5. Winter flounder catch (# fish) in the standardized TDD from March 2011 through March 2014 at 11 stations consistently sampled in Closed Area I (CAI).

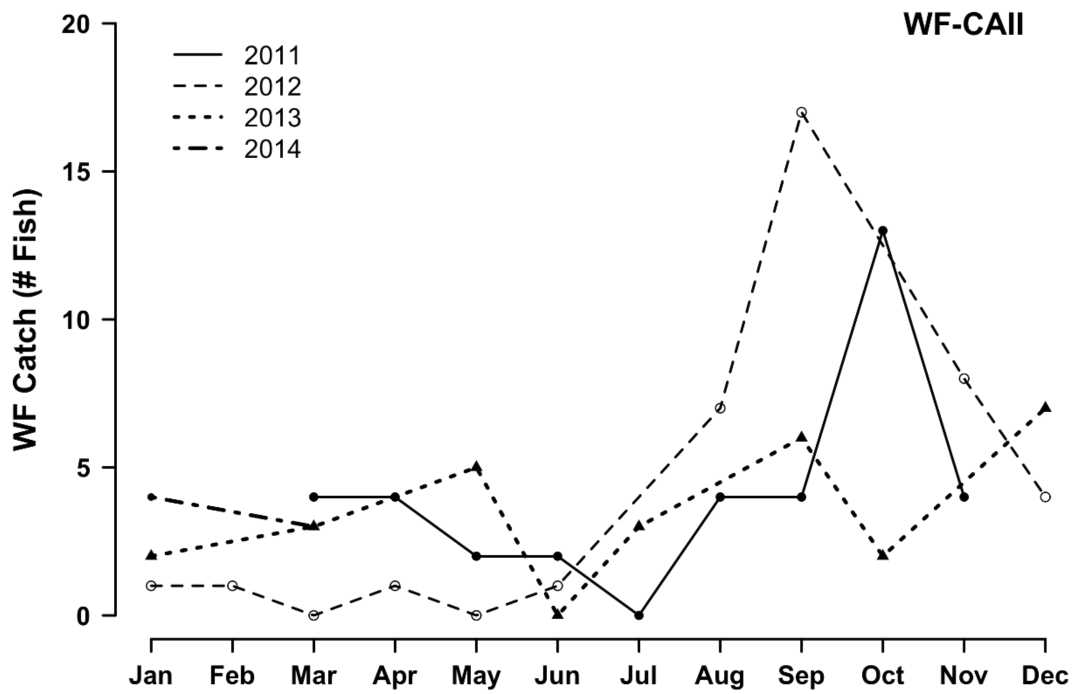


Figure C-6. Winter flounder catch (# fish) in the standardized TDD from March 2011 through March 2014 at 23 stations consistently sampled in Closed Area II (CAII).

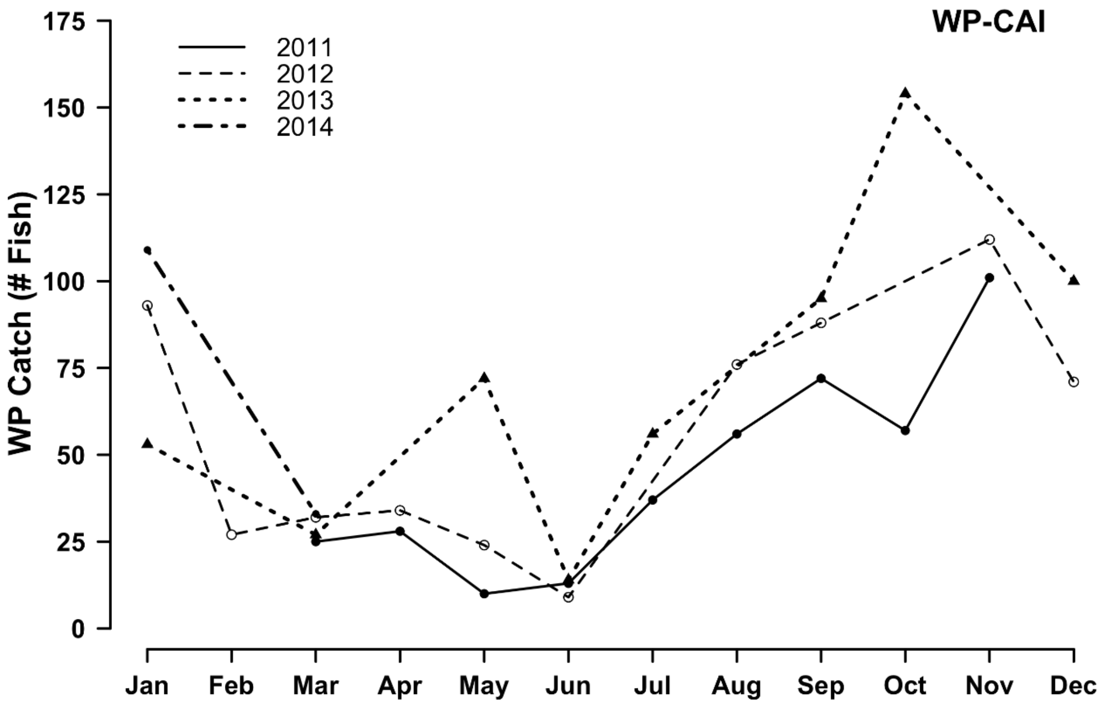


Figure C-7. Windowpane flounder catch (# fish) in the standardized TDD from March 2011 through March 2014 at 11 stations consistently sampled in Closed Area I (CAI).

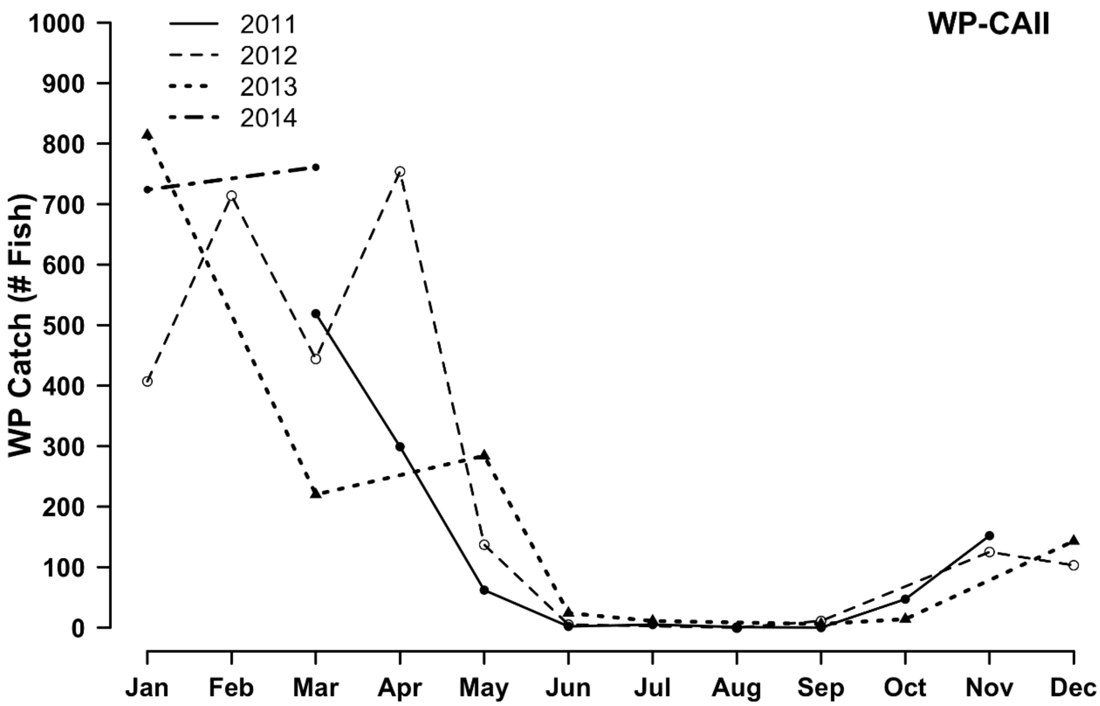


Figure C-8. Windowpane flounder catch (# fish) in the standardized TDD from March 2011 through March 2014 at 23 stations consistently sampled in Closed Area II (CAII).

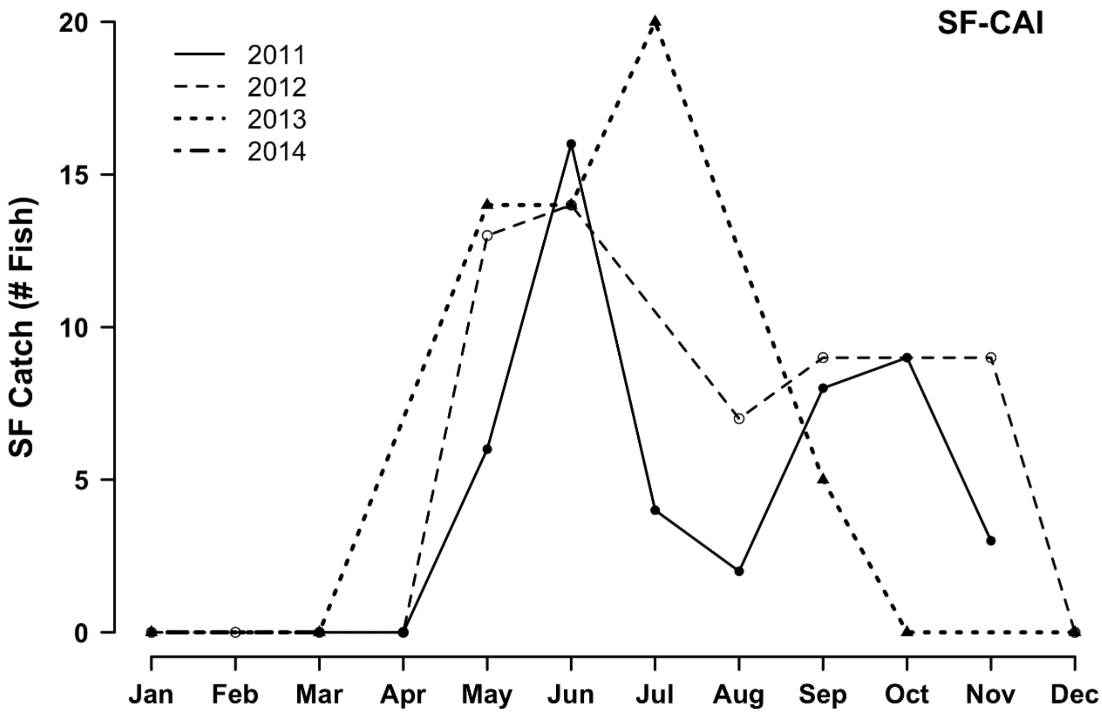


Figure C-9. Summer flounder catch (# fish) in the standardized TDD from March 2011 through March 2014 at 11 stations consistently sampled in Closed Area I (CAI).

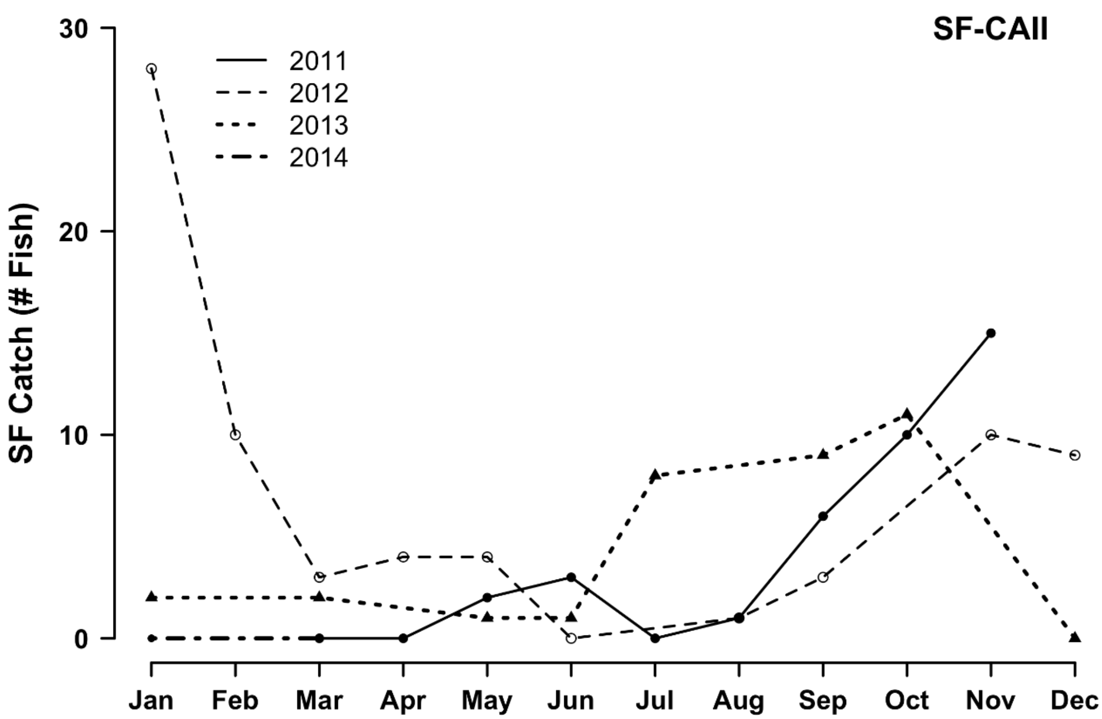


Figure C-10. Summer flounder catch (# fish) in the standardized TDD from March 2011 through March 2014 at 23 stations consistently sampled in Closed Area II (CAII).

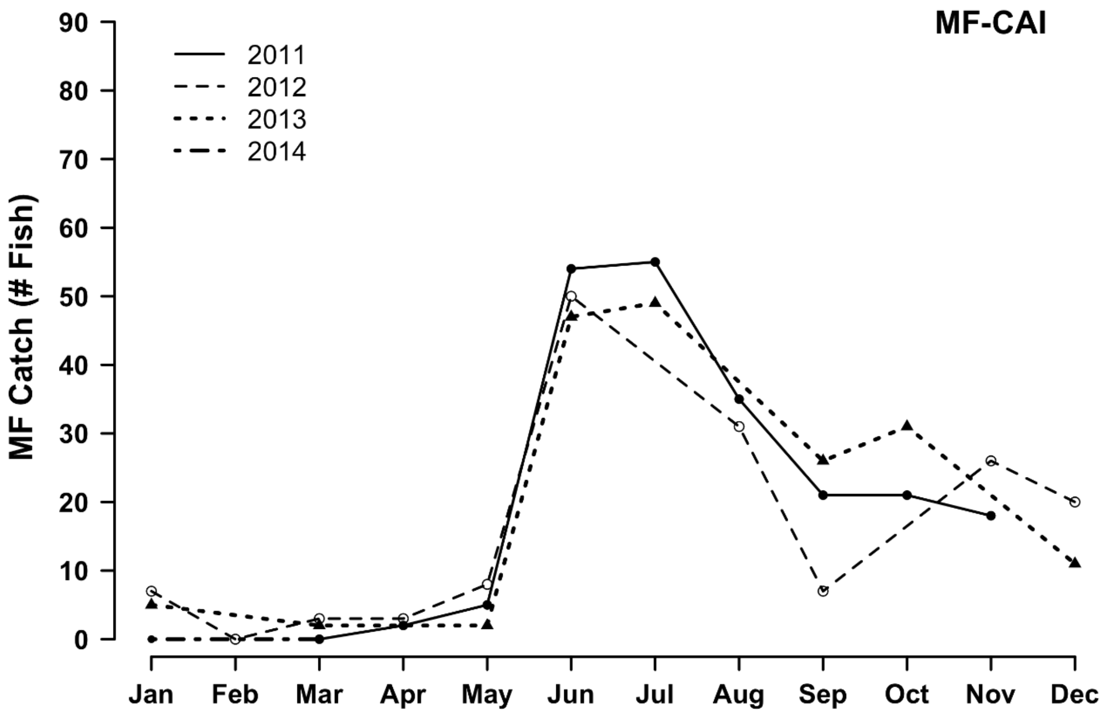


Figure C-11. Monkfish catch (# fish) in the standardized TDD from March 2011 through March 2014 at 11 stations consistently sampled in Closed Area I (CAI).

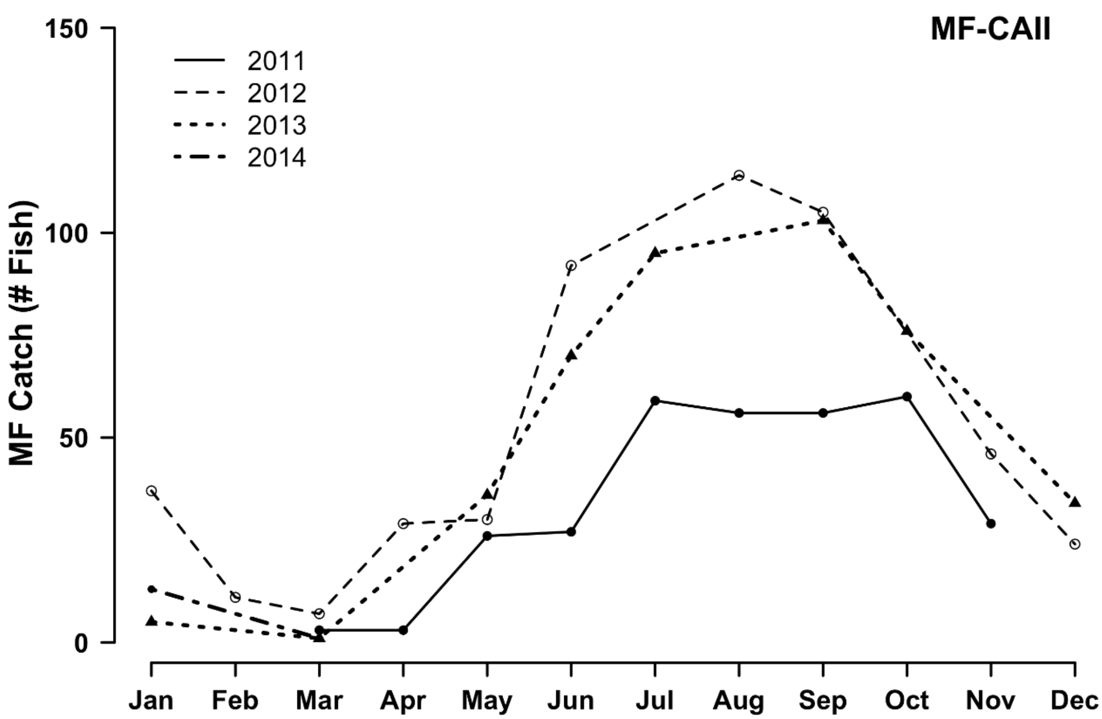


Figure C-12. Monkfish catch (# fish) in the standardized TDD from March 2011 through March 2014 at 23 stations consistently sampled in Closed Area II (CAII).

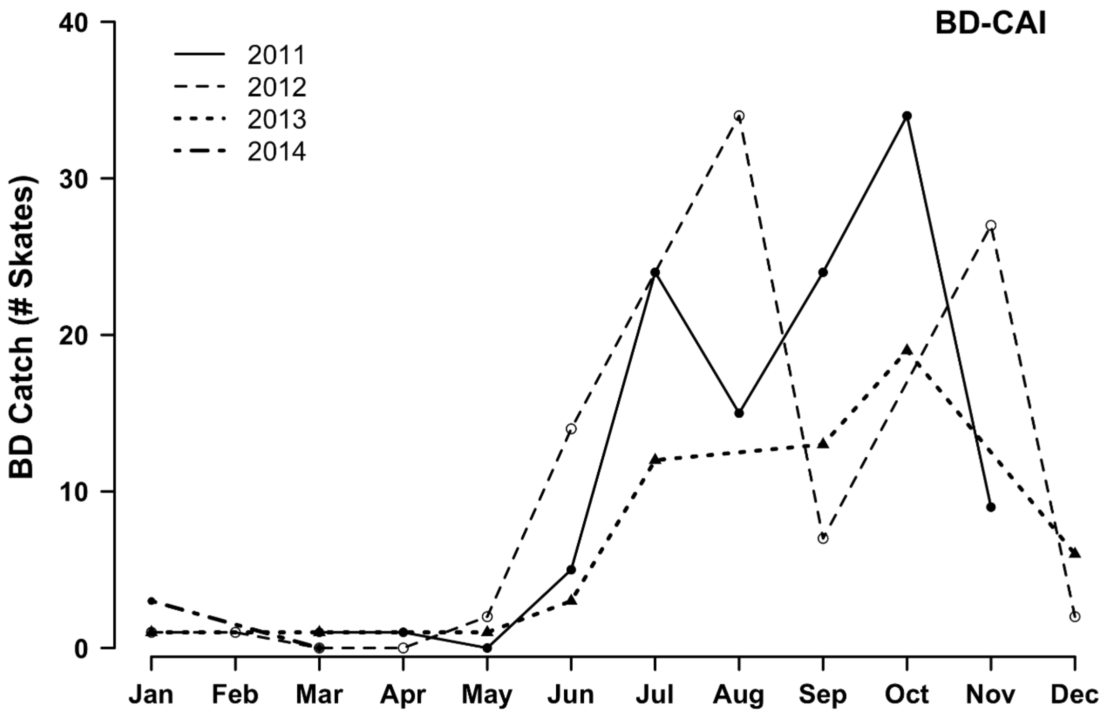


Figure C-13. Barndoor skate catch (# skates) in the standardized TDD from March 2011 through March 2014 at 11 stations consistently sampled in Closed Area I (CAI).

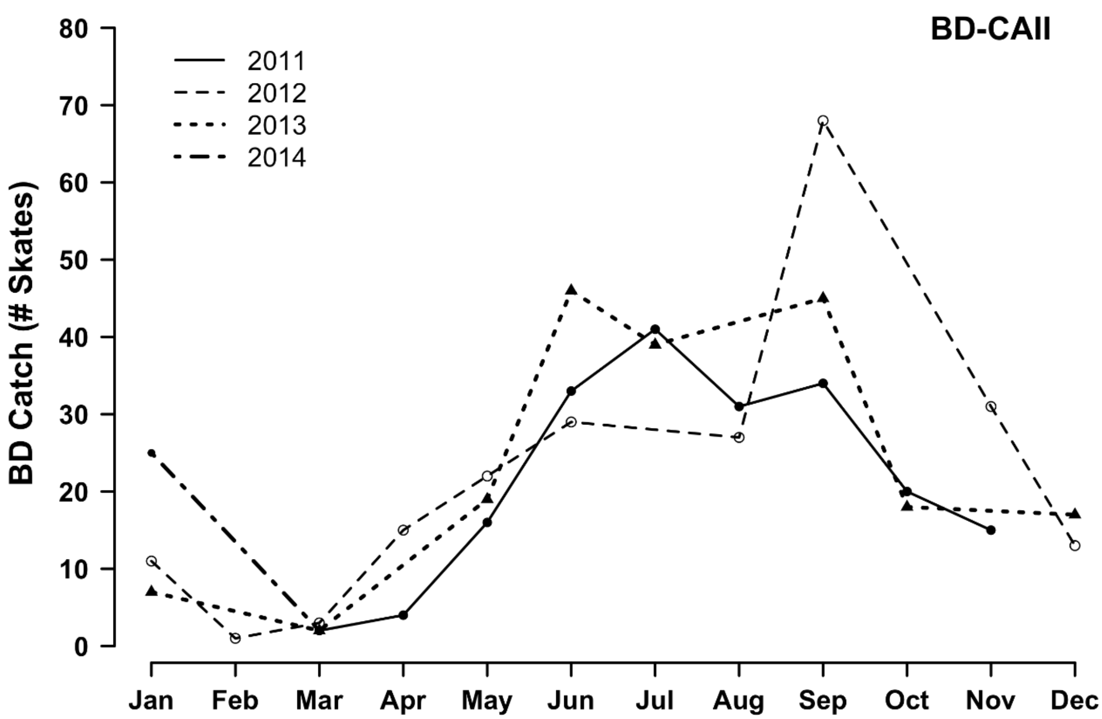


Figure C-14. Barndoor skate catch (# skates) in the standardized TDD from March 2011 through March 2014 at 23 stations consistently sampled in Closed Area II (CAII).

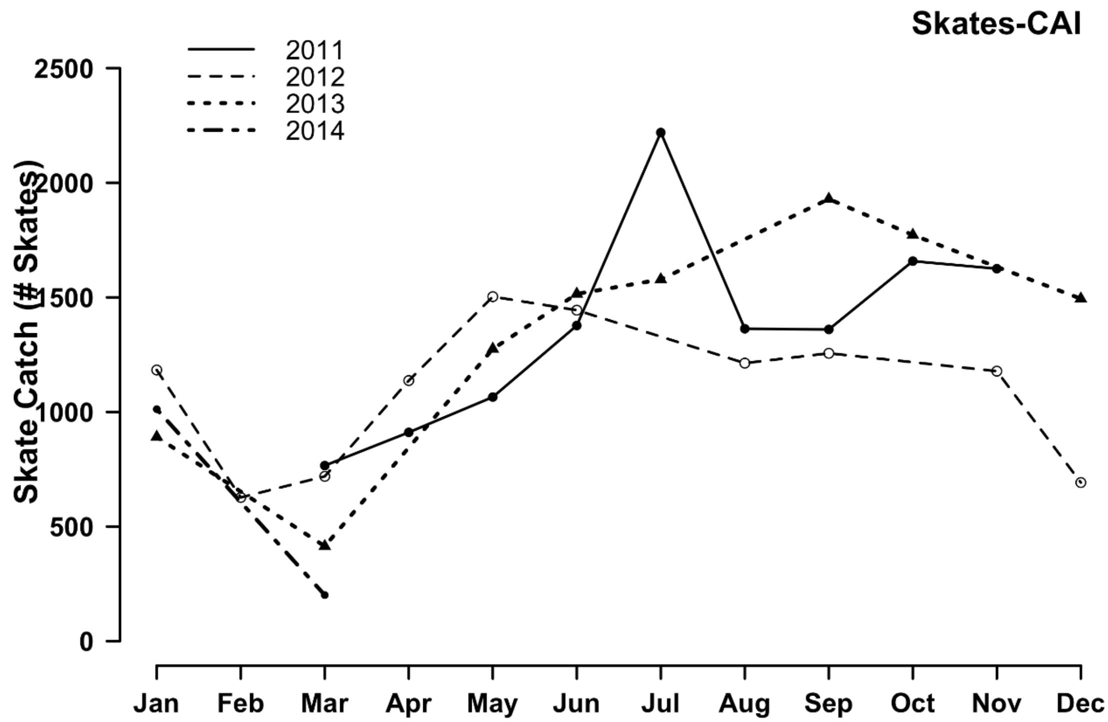


Figure C-15. Unclassified skate catch (# skates) in the standardized TDD from March 2011 through March 2014 at 11 stations consistently sampled in Closed Area I (CAI).

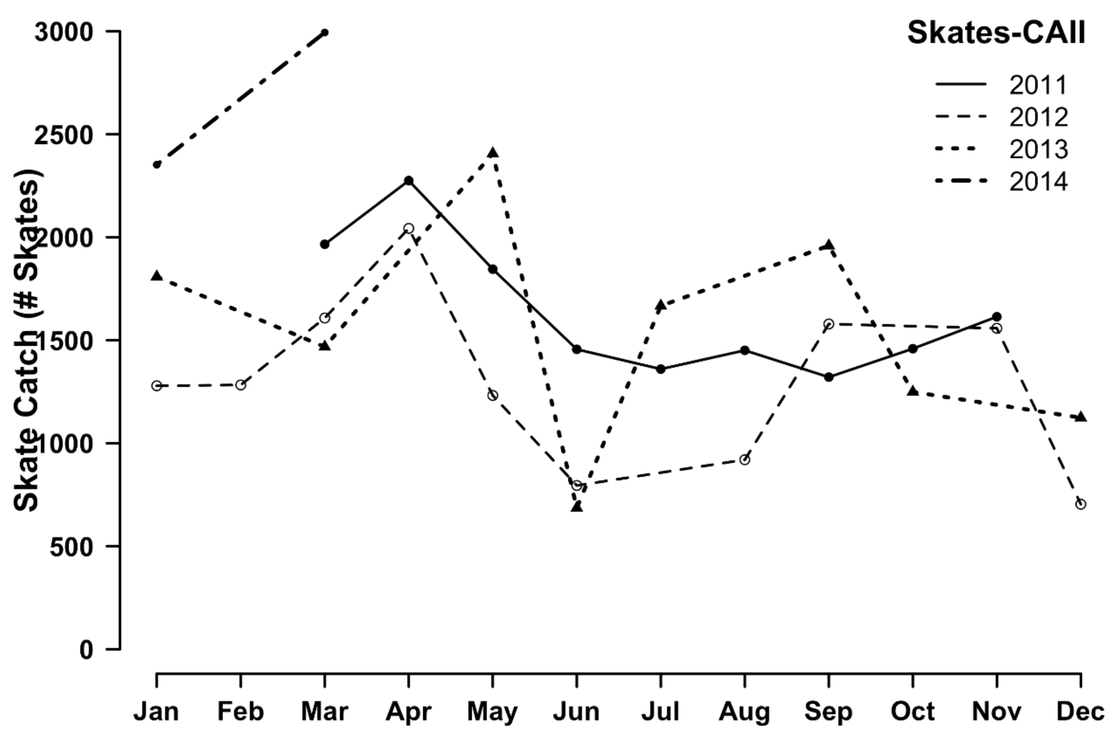


Figure C-16 Unclassified skate catch (# skates) in the standardized TDD from March 2011 through March 2014 at 23 stations consistently sampled in Closed Area II (CAII).

Appendix D.
Additional information on gear comparisons
Catch data from the paired tows provided the information to estimate differences in the relative efficiency for the gear combinations tested. This analysis is based on the analytical approach in Cadigan et al. 2006.

Assume that each gear combination tested in this experiment has a unique catchability. Let q_r equal the catchability of the turtle deflector dredge (TDD) and q_f equal the catchability of the New Bedford style dredge (NBD) used in the study. The efficiency of the TDD relative to the NBD will be equivalent to the ratio of the two catchabilities:

$$\rho_l = \frac{q_r}{q_f} \qquad (1)$$

The catchabilities of each gear are not measured directly. However, within the context of the paired design, assuming that spatial heterogeneity in scallop/fish and fish density is minimized, observed differences in scallop/fish catch for each vessel will reflect differences in the catchabilities of the gear combinations tested.

Let C_{iv} represent the scallop/fish catch at station *i* by dredge *v*, where *v*=*r* denotes the TDD dredge and *v*=*f* denotes the NBD. Let λ_{ir} represent the scallop/fish density for the i^{th} station by the TDD and λ_{if} the scallop/fish density encountered by the NBD. We assume that due to random or unknown, small scale variability in animal density as well as the vagaries of gear performance at tow *i*, the densities encountered by the two gears may vary as a result of small-scale spatial heterogeneity as reflected by the relationship between scallop/fish patch size and coverage by a paired tow. The probability that a scallop/fish is captured during a standardized tow is given as q_r and q_f. These probabilities can be different for each vessel, but are expected to be constant across stations. Assuming that capture is a Poisson process with mean equal to variance, then the expected catch by the NBD is given by:

$$E(C_{if}) = q_f \lambda_{if} = \mu_i \qquad (2)$$

The catch by the NB dredge is also a Poisson random variable with:

$$E(C_{ir}) = q_r \lambda_{ir} = \rho \mu_i \exp(\delta_i) \qquad (3)$$

where $\delta_i = \log(\lambda_{ir}/\lambda_{if})$. For each station, if the standardized density of scallops /fish encountered by both dredges is the same, then δ_i=0.

If the dredges encounter the same scallop/fish density for a given tow, (i.e. $\lambda_{ir} = \lambda_{if}$), then ρ can be estimated via a Poisson generalized linear model (GLM). This approach, however, can be complicated especially if there are large numbers of stations and scallop/fish lengths (Cadigan et al. 2006). The preferred approach is to use the conditional distribution of the catch by the TDD at station *i*, given the total non-zero catch of both vessels at that station. Let c_i represent the observed value of the total catch. The conditional distribution of C_{ir} given $C_i=c_i$ is binomial with:

$$\Pr\left(C_{ic} = x \middle| C_i = c_i\right) = \binom{c_i}{x} p^x (1-p)^{r_i - x} \quad (4)$$

where $p=\rho/(1+\rho)$ is the probability that a scallop/fish is captured by the TDD dredge. In this approach, the only unknown parameter is ρ and the requirement to estimate μ for each station is eliminated as would be required in the direct GLM approach (equations 2 & 3). For the binomial distribution $E(C_{ir})=c_i p$ and $Var(C_i r)=c_i p/(1-p)$. Therefore:

$$\log\left(\frac{p}{1-p}\right) = \log(\rho) = \beta \quad (5)$$

The model in equation 5, however, does not account for spatial heterogeneity in the densities encountered by the two gears for a given tow. If such heterogeneity does exist then the model becomes:

$$\log\left(\frac{p}{1-p}\right) = \beta + \delta_i \quad (6)$$

where δ_i is a random effect assumed to be normally distributed with a mean=0 and variance=σ^2. This model is the formulation used to estimate the gear effect $exp(\beta_0)$ when catch per tow is pooled over lengths.

Often, gear modifications can result in changes to the length based relative efficiency of the two gears. In those instances, the potential exists for the catchability at length (*l*) to vary. Models to describe length effects are extensions of the models in the previous section to describe the total scallop catch per tow. Again, assuming that between-pair differences in standardized animal density exist, a binomial logistic regression GLMM for a range of length groups would be:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \delta_i + \beta_1 l, \delta_i \sim N(0,\sigma^2), i = 1,\ldots,n. \quad (7)$$

In this model, the intercept (β_0) is allowed to vary randomly with respect to station.
The potential exists, however, that there will be variability in both the number as well as the length distributions of scallops/fish encountered within a tow pair. In this situation, a random effects model that again allows the intercept to vary randomly between tows is appropriate (Cadigan and Dowden 2009). This model is given below:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \delta_{i0} + \beta_1 * l, \delta_{ij} \sim N(0,\sigma_j^2), i = 1,\ldots,n, j = 0,1. \quad (8)$$

Adjustments for sub-sampling of the catch

Additional adjustments to the models were required to account for sub-sampling of the catch. In most instances, due to high scallop catch volume. All tows with more than one bushel were subsampled. This is accomplished by randomly selecting a one bushel sample for length frequency analysis. The total catch of finfish was always measured without subsampling. One approach to accounting for this practice is to use the expanded catches. For example, if half of the total catch was measured for length frequency, multiplying the observed catch by two would result in an estimate of the total catch at length for the tow. This approach would overinflate the sample size resulting in an underestimate of the variance, increasing the chances of spurious statistical inference (Millar et al. 2004; Holst and Revill 2009). In our experiment, the proportion sub-sampled was not consistent between tows as only a one bushel sub-sample was taken regardless of catch size. This difference must be accounted for in the analysis to ensure that common units of effort are compared.

Let q_{ir} equal the sub-sampling fraction at station *i* for the vessel *r*. This adjustment results in a modification to the logistic regression model:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0, \sigma_j^2), i = 1, ..., n. \quad (9)$$

The last term in the model represents an offset in the logistic regression (Littell et al. 2006).

Our analysis of the efficiency of the TDD relative to the NBD consisted of multiple levels of examination. For all species, the full model consisted of unpooled (by length) catch data:

$$\log\left(\frac{p_i}{1+p_i}\right) = \beta_0 + \delta_i + (\beta_1 * l_i) + \log\left(\frac{q_{ir}}{q_{if}}\right), \delta_{ij} \sim N(0, \sigma_j^2), i = 1..n, j = 0,1 \ldots (10)$$

Model fit was assessed by AIC. If AIC and factor significance indicated that length was not a significant factor in predicting relative efficiency, the data was pooled over length. The random intercept model was evaluated to assess relative differences in total catch (see equation 6).

Table D-1 Model building results for each species examined in the analysis. Fixed effects included in the model indicate the specification that resulted in the lowest AIC value for that particular species. AIC values that were within two units of each other were considered indistinguishable and the simpler model was chosen. Random effects are shown in brackets and were included at the station level. Species where the model failed to converge are indicated.

Species	**Model Specification**
Spiny Dogfish	RE_{TDD} ~ intercept +[station]
Barndoor Skate	RE_{TDD} ~ intercept +[station]
Unclassified Skates	RE_{TDD} ~ intercept +[station]
Atlantic Cod	RE_{TDD} ~ intercept +[station]
Haddock	RE_{TDD} ~ intercept +[station]
American Plaice	RE_{TDD} ~ intercept +[station]
Summer Flounder	RE_{TDD} ~ intercept +[station]
Fourspot Flounder	RE_{TDD} ~ intercept +[station]
Yellowtail Flounder	RE_{TDD} ~ intercept +[station]
Blackback Flounder	RE_{TDD} ~ intercept +[station]
Grey Sole	Did Not Converge
Windowpane Flounder	RE_{TDD} ~ intercept + length + [station]
Monkfish	RE_{TDD} ~ intercept +[station]
Sea Scallops	RE_{TDD}~ intercept + length + [station]

Table D- 2 Mixed effects model using the unpooled catch data . Results are for from the model that provided the best fit (intercept and length) to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale.

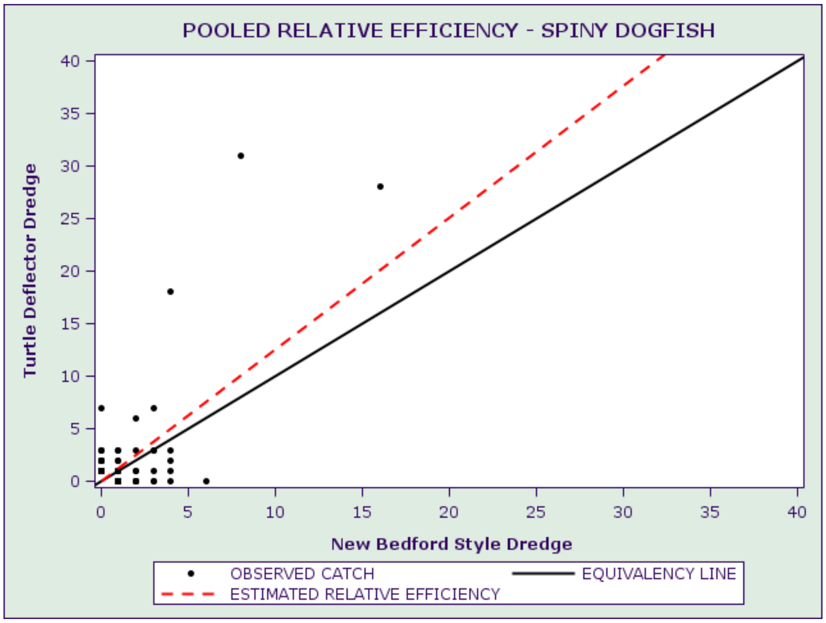
Species	**Effect**	**Estimate**	**SE**	**DF**	**t-**	**p-**	**LCI**	**UCI**
Spiny	Intercept	-0.675	0.607	271	-1.113	0.267	-1.869	0.519
	Size	0.016	0.010	271	1.552	0.122	-0.004	0.036
Barndoor	Intercept	0.220	0.114	2192	1.932	0.053	-0.003	0.443
	Size	-0.002	0.002	2192	-1.137	0.256	-0.006	0.002
Atlantic Cod	Intercept	-2.970	5.178	27	-0.574	0.571	-	7.654
	Size	0.004	0.084	27	0.046	0.964	-0.168	0.175
Haddock	Intercept	-0.681	0.498	148	-1.368	0.173	-1.665	0.303
	Size	0.017	0.025	148	0.673	0.502	-0.033	0.067
American	Intercept	-1.645	1.269	157	-1.296	0.197	-4.152	0.861
	Size	0.042	0.033	157	1.262	0.209	-0.024	0.107
Summer	Intercept	-0.114	0.600	414	-0.190	0.849	-1.293	1.065
	Size	0.004	0.011	414	0.345	0.730	-0.018	0.025
Fourspot	Intercept	0.350	0.376	1067	0.932	0.352	-0.387	1.087
	Size	-0.011	0.011	1067	-1.009	0.313	-0.034	0.011
Yellowtail	Intercept	-0.314	0.340	2148	-0.925	0.355	-0.980	0.352
	Size	0.007	0.009	2148	0.748	0.454	-0.011	0.024
Winter	Intercept	0.349	0.508	840	0.687	0.493	-0.648	1.345
	Size	-0.011	0.012	840	-0.878	0.380	-0.034	0.013
Windowpane	**Intercept**	**0.428**	**0.212**	**3202**	**2.017**	**0.044**	**0.012**	**0.844**
	Size	**-0.017**	**0.008**	**3202**	**-2.289**	**0.022**	**-0.032**	**-**
Monkfish	Intercept	0.034	0.157	3704	0.215	0.830	-0.274	0.342
	Size	0.000	0.003	3704	-0.137	0.891	-0.006	0.006
Sea Scallop	**Intercept**	**-0.149**	**0.047**	**9670**	**-3.157**	**0.002**	**-0.242**	**-**
	Size	**0.001**	**0.000**	**9670**	**2.802**	**0.005**	**0.000**	**0.002**

<u>Table D-3</u> Mixed effects model (random intercept) using the pooled catch data . Results are for from the model that provided the best fit to the data as supported by model comparison (minimum AIC value). Confidence limits are Wald type confidence intervals. Parameter estimates are on the logit scale and the exp(Estimate) is the estimated relative efficiency on the probability scale. Percent change represents the average percentage change in the catch of the TDD relative to the NBD. Significant parameters are shown in bold.

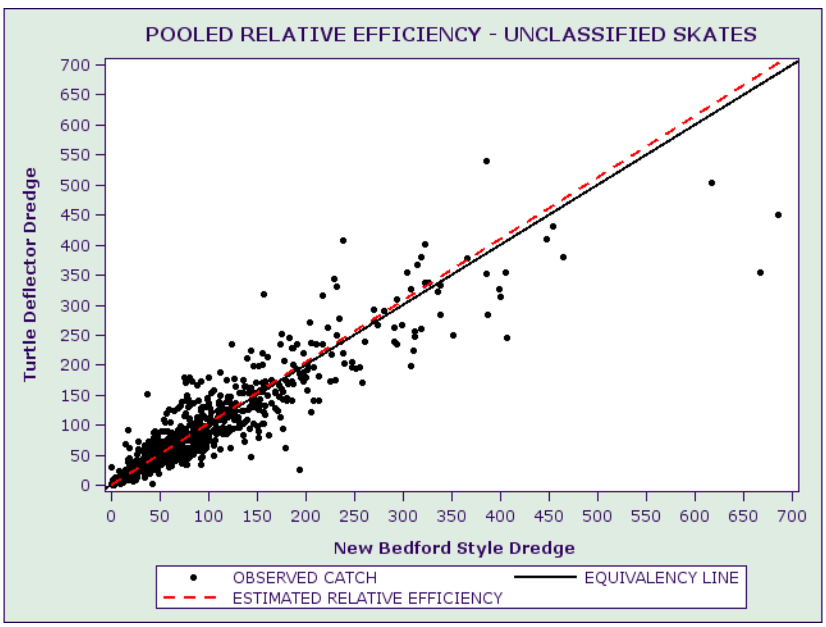
Species	**Estimate**	**SE**	**DF**	**t-value**	**p-value**	**LCI**	**UCI**	**exp(Est)**	**% Change**
Spiny Dogfish	0.227	0.177	134	1.280	0.203	-0.124	0.578	1.255	25.5%
Unclassified Skates	0.025	0.013	727	1.856	0.064	-0.001	0.051	1.025	2.5%
Barndoor Skate	**0.100**	**0.043**	**445**	**2.350**	**0.019**	**0.016**	**0.184**	1.105	10.5%
Atlantic Cod	-2.751	1.884	25	-1.460	0.157	-6.632	1.130	0.064	-93.6%
Haddock	-0.383	0.214	95	-1.789	0.077	-0.808	0.042	0.682	-31.8%
American Plaice	-0.054	0.164	106	-0.327	0.744	-0.379	0.272	0.948	-5.2%
Summer Flounder	0.090	0.098	153	0.918	0.360	-0.104	0.284	1.094	9.4%
Fourspot Flounder	-0.023	0.063	338	-0.368	0.713	-0.148	0.101	0.977	-2.3%
Yellowtail Flounder	-0.067	0.036	463	-1.885	0.060	-0.137	0.003	0.935	-6.5%
Winter Flounder	-0.094	0.065	268	-1.438	0.152	-0.222	0.035	0.910	-9.0%
Windowpane Flounder	**-0.056**	**0.025**	**493**	**-2.284**	**0.023**	**-0.105**	**-0.008**	0.945	-5.5%
Monkfish	0.013	0.030	544	0.417	0.677	-0.047	0.072	1.013	1.3%
Sea Scallop	-0.021	0.012	716	-1.785	0.075	-0.044	0.002	0.979	-2.1%

Table D-4. Total catch during each survey cruise for select species between the turtle deflector dredge (TDD) and the New Bedford style dredge (NBD). Units for scallops is bushels and fish were recorded as total number. Significant values are displayed in red (> 0.05 Wilcoxon (signed-rank)).

	Scallops (bu)			Yellowtail Flounder			Windowpane Flounder			Winter Flounder			Barndoor Skate		
	TDD	NBD	p value	TDD	NBD	p value	TDD	NBD	p value	TDD	NBD	p value	TDD	NBD	p value
May	288.7	262.1	0.000	168	169	0.815	638	546	0.026	19	21	0.823	133	157	0.435
Jun	265.8	263.4	0.276	145	144	0.877	93	93	0.666	58	65	0.516	215	187	0.202
Jul	293.5	298.4	0.786	203	181	0.138	254	209	0.627	129	116	0.638	210	191	0.335
Sep	258.8	256.4	0.821	387	408	0.367	315	321	0.679	95	108	0.236	270	216	0.070
Oct	242.7	246.8	0.994	304	397	0.045	333	452	0.002	85	90	0.550	181	162	0.298
Dec	204.0	205.0	0.830	146	165	0.353	628	695	0.126	87	103	0.334	148	122	0.176
Jan	219.3	218.1	0.445	238	256	0.687	1702	1936	0.002	18	28	0.149	155	153	0.658
Mar	214.0	224.3	0.178	142	135	0.950	1758	1877	0.716	7	13	0.234	29	27	0.944



<u>Figure D-1</u> Total pooled catches for Spiny Dogfish for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.



<u>Figure D-2</u> Total pooled catches for Unclassified Skates for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

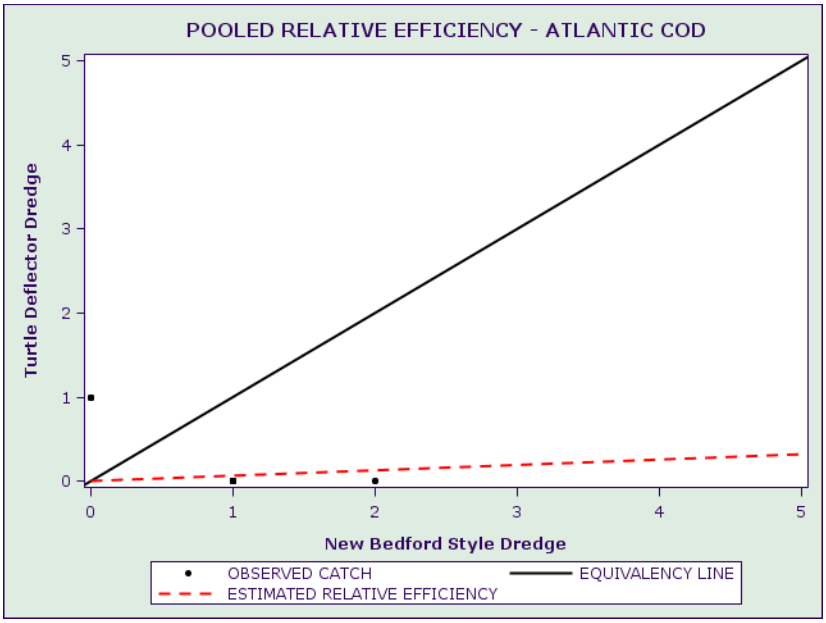


Figure D-3 Total pooled catches for Atlantic cod for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

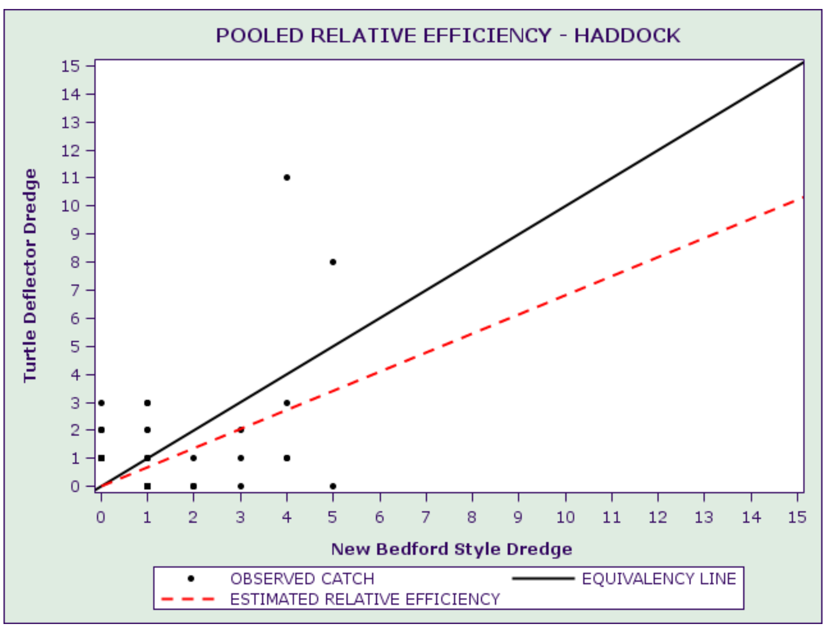


Figure D-4 Total pooled catches for haddock for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

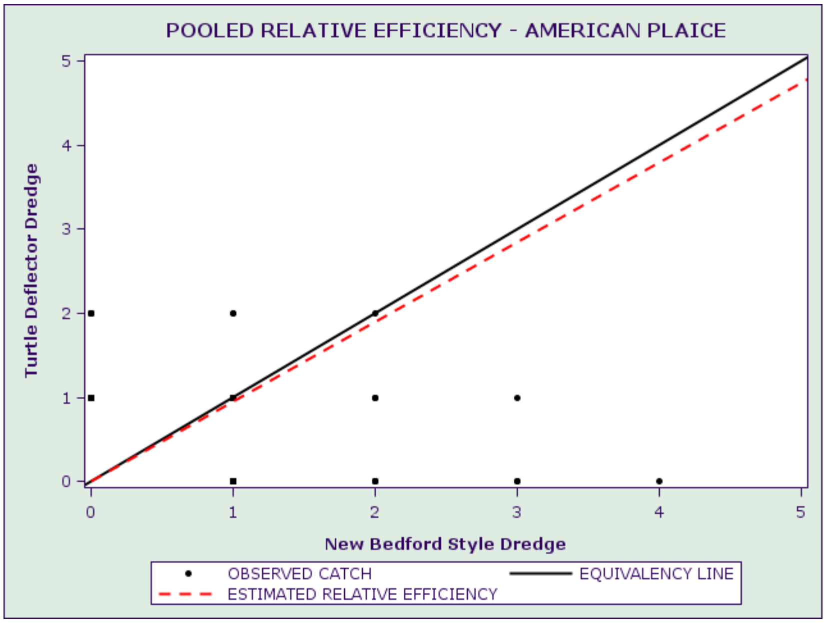


Figure D-5 Total pooled catches for American plaice for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

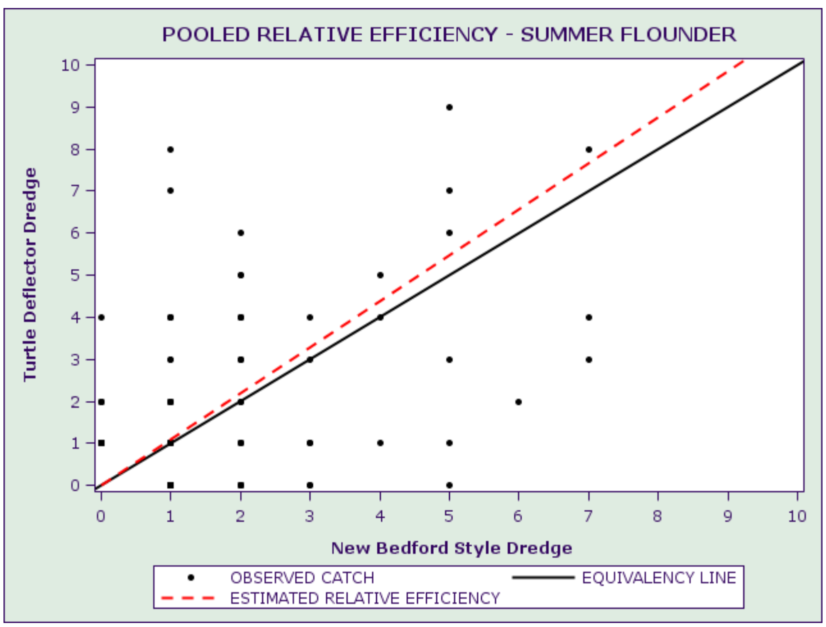


Figure D-6 Total pooled catches for summer flounder for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

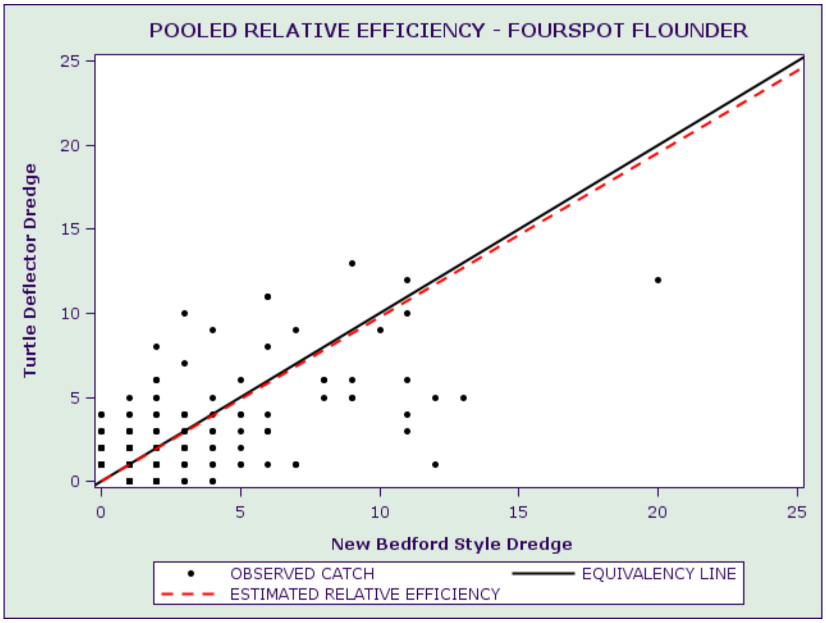


Figure D-7 Total pooled catches for fourspot flounder for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

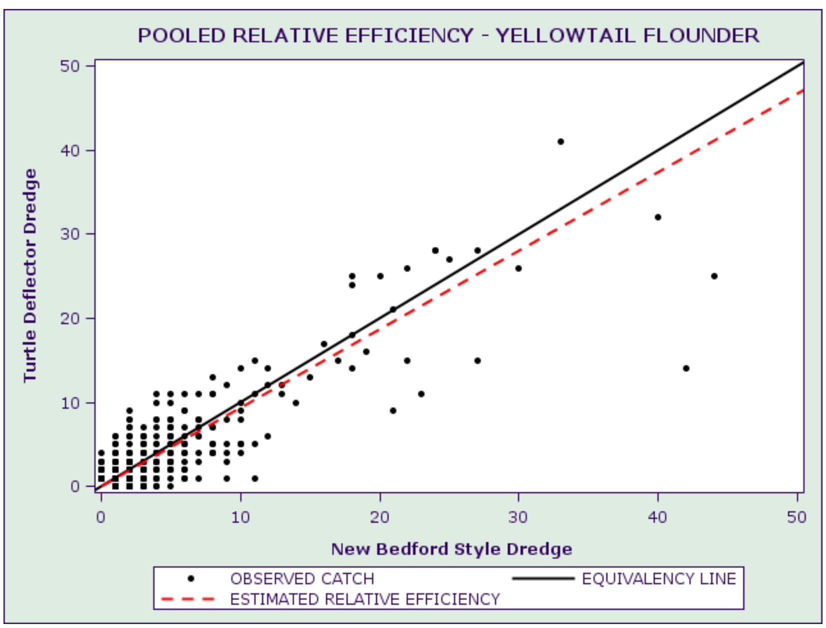


Figure D-8 Total pooled catches for yellowtail flounder for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

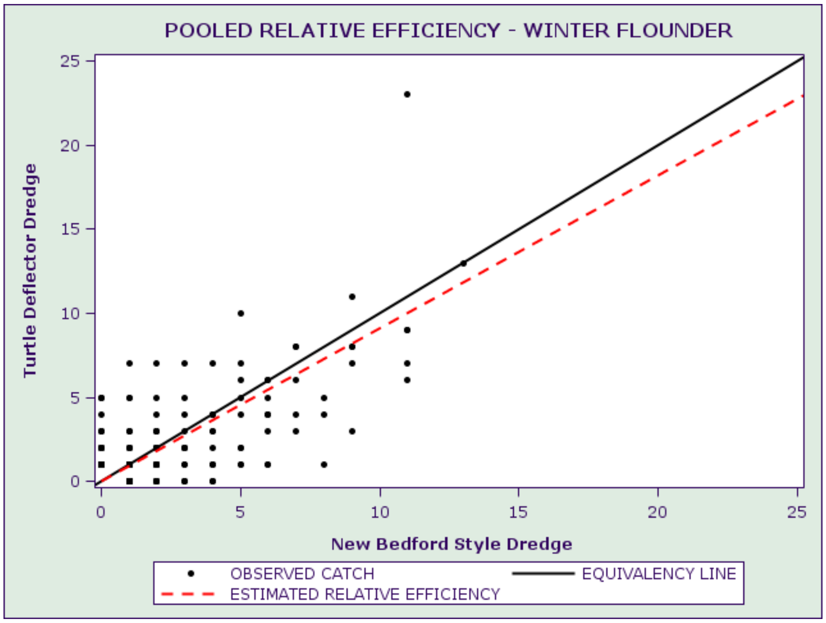


Figure D-9 Total pooled catches for winter flounder for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.

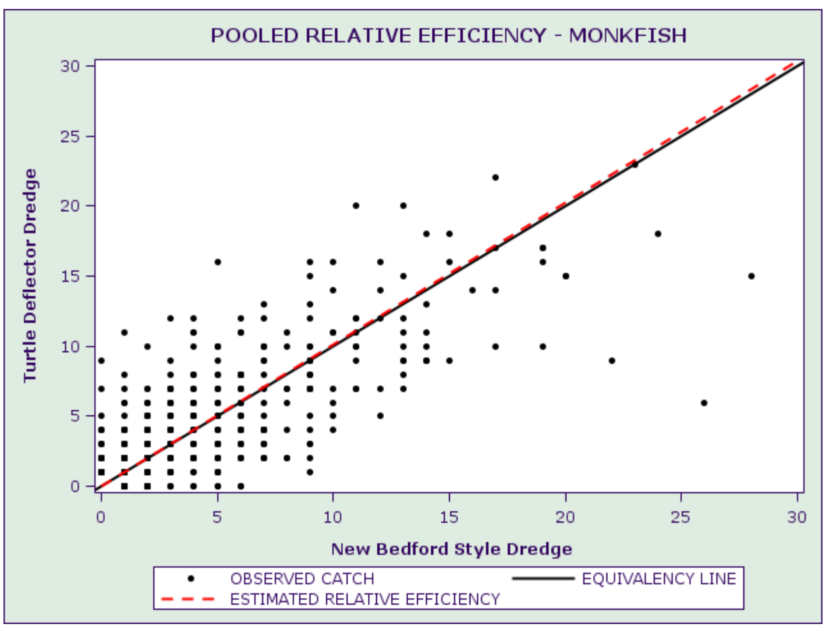
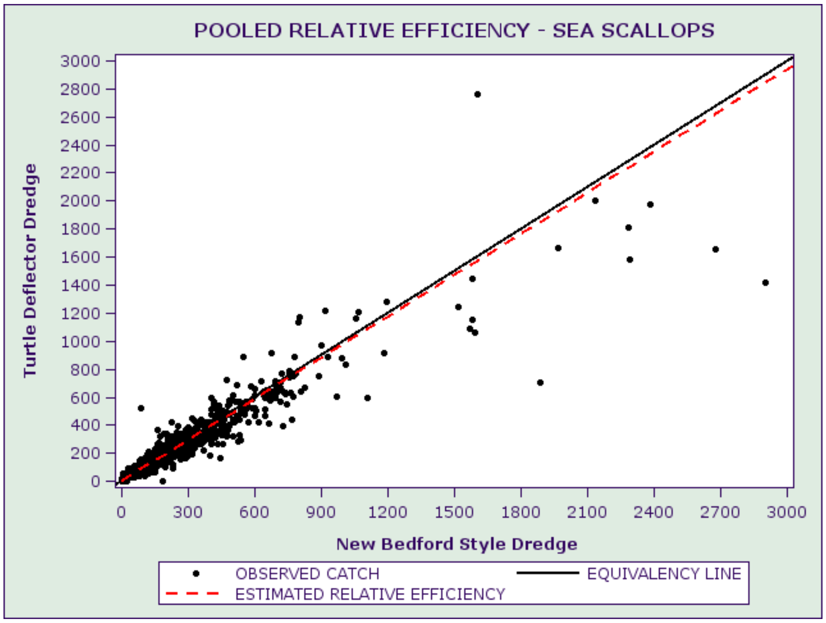


Figure D-10 Total pooled catches for monkfish for the TDD vs. the NBD. Model output from the analysis of the pooled data indicated that the intercept only model was the most appropriate specification. The estimated relative efficiency is show as the red dashed line. The black line has a slope of one.



<u>Figure D-11</u> Total pooled catches for sea scallop for the TDD vs. the NBD. Model output indicated that the intercept only model was not the most appropriate specification. However, it is informative to see that the total catch of this species did differ between dredges in addition to a significantly different length relationship.

Appendix E: Additional data for shell height meat weight relationship

Table E-1 Results from iterative model building. Model with the minimum AIC value is shown in bold. Fixed effects are shown to the right of the ~ symbol. This symbol separates the response (Meat Weight) from the predictor variables used in the analysis. Interaction terms are denoted with the factor1*factor2 nomenclature. For the models that included a random effect, this effect was always evaluated at the station level. The best fitting model was also evaluated without a random effect to assess the impact of including a random effect in the model.

Fixed Effects	Random effect	AIC	BIC	-2 log Likelihood
Meat Weight ~Shell Height + Depth + Month + Location + Depth *Location	**Intercept**	**21417**	**21475**	**20828**
Meat Weight ~Shell Height + Depth + Month + Shell Height * Depth	Intercept	21543	21590	20792
Meat Weight ~Shell Height + Depth + Month + Location + Shell Height * Depth	Intercept	21545	21600	20792
Meat Weight ~Shell Height + Depth + Month	Intercept	21546	21589	20797
Meat Weight ~ Shell Height + Month	Intercept	21547	21587	20796
Meat Weight ~Shell Height + Depth + Month + Location + Shell Height * Location	Intercept	21547	21605	20791
Meat Weight ~Shell Height + Depth + Month + Location	Intercept	21548	21599	20797
Meat Weight ~Shell Height + Depth + Month + Shell Height *Month	Intercept	21549	21618	20787
Meat Weight ~Shell Height + Month + Location	Intercept	21550	21597	20797
Meat Weight ~Shell Height + Month + Location + Shell Height * Location	Intercept	21551	21605	20795
Meat Weight ~ Shell Height + Month + Shell Height * Month	Intercept	21552	21617	20788
Meat Weight ~Shell Height + Depth + Month + Location + Shell Height * Month	Intercept	21552	21628	20788
Meat Weight ~Shell Height + Depth + Month + Depth *Month	Intercept	21554	21623	20798
Meat Weight ~Shell Height + Month + Location + Shell Height * Month	Intercept	21554	21626	20788
Meat Weight ~Shell Height + Depth + Month + Location + Depth * Month	Intercept	21556	21632	20798
Meat Weight ~Shell Height + Depth + Month + Location + Month *Location	Intercept	21560	21662	20800
Meat Weight ~Shell Height + Month + Location + Month * Location	Intercept	21563	21660	20800
Table E-1 Cont.				

Fixed Effects	Random effect	AIC	BIC	-2 log Likelihood
Meat Weight ~Shell Height + Depth + Location + Depth * Location	Intercept	21596	21629	20785
Meat Weight ~Shell Height + Depth + Shell Height * Depth	Intercept	21662	21684	20772
Meat Weight ~ Shell Height + Depth	Intercept	21665	21684	20776
Meat Weight ~Shell Height + Location + Shell Height * Location	Intercept	21665	21694	20766
Meat Weight ~Shell Height + Depth + Location + Shell Height * Depth	Intercept	21665	21694	20772
Meat Weight ~Shell Height + Depth + Location + Shell Height * Location	Intercept	21665	21697	20766
Meat Weight ~ Shell Height	Intercept	21666	21681	20776
Meat Weight ~Shell Height + Depth + Location	Intercept	21668	21694	20777
Meat Weight ~ Shell Height + Location	Intercept	21669	21691	20776
Meat Weight ~Shell Height + Depth + Month + Location + Depth *Location	None	21690	21781	21660
Meat Weight ~ Location + Depth + Month + Location*Depth	Intercept	24760	24814	24124
Meat Weight ~ Depth + Location + Depth * Location	Intercept	24831	24860	24105
Meat Weight ~ Location + Month	Intercept	24865	24909	24101
Meat Weight ~ Location + Depth + Month	Intercept	24866	24913	24102
Meat Weight ~ Depth + Month	Intercept	24869	24909	24100
Meat Weight ~ Month	Intercept	24873	24909	24099
Meat Weight ~ Location + Depth + Month + Depth * Month	Intercept	24875	24947	24103
Meat Weight ~ Depth + Month + Depth * Month	Intercept	24877	24942	24101
Meat Weight ~ Location + Month + Location * Month	Intercept	24881	24975	24103
Meat Weight ~ Location + Depth + Month + Location*Month	Intercept	24882	24979	24104
Meat Weight ~ Location	Intercept	24915	24934	24091
Meat Weight ~ Depth + Location	Intercept	24916	24938	24092
Meat Weight ~ Depth	Intercept	24918	24932	24091
Meat Weight ~	Intercept	24921	24931	24090

<u>Table E-2</u> Parameter estimates for the best model as described by minimum AIC value. For the categorical variables (Trip Month, Location), differences within that category are relative to the value with a 0 parameter estimate (i.e. Open Area and September 2014). Similarly, p-values within a category are relative to that standard and not for the whole model. All included fixed effects were significant overall.

Effect	**Location**	**Trip Month**	**Estimate**	**SE**	**DF**	**t-value**	**p-value**
Intercept			-4.687	0.538	266	-8.709	<0.001
Shell Height			2.356	0.031	3070	76.531	<0.001
Depth			-0.767	0.121	3070	-6.332	<0.001
Trip_Month		July 2013	0.078	0.023	3070	3.455	0.001
Trip_Month		June 2013	0.163	0.023	3070	7.221	<0.001
Trip_Month		May 2013	0.026	0.023	3070	1.138	0.255
Trip_Month		March 2014	0.041	0.023	3070	1.818	0.069
Trip_Month		January 2014	-0.128	0.023	3070	-5.613	<0.001
Trip_Month		October 2014	-0.115	0.023	3070	-5.091	<0.001
Trip_Month		December 2014	-0.081	0.023	3070	-3.578	<0.001
Trip_Month		September 2014	0.000				
Location	CAI		-5.527	0.571	3070	-9.687	<0.001
Location	CAII		-0.653	0.679	3070	-0.961	0.337
Location	Open Area		0.000				
Depth*Location	CAI		1.296	0.133	3070	9.726	<0.001
Depth*Location	CAII		0.145	0.158	3070	0.920	0.358
Depth*Location	Open Area		0.000				

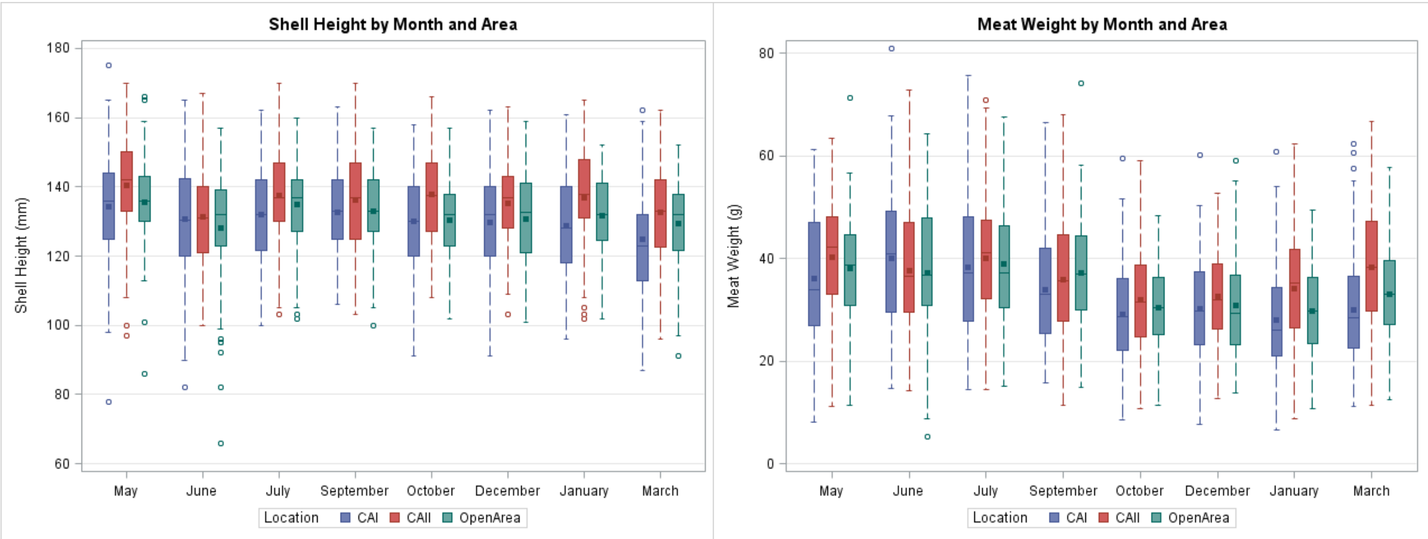


Figure E-1 Spatial and temporal distribution of collected shell height and meat weight samples.

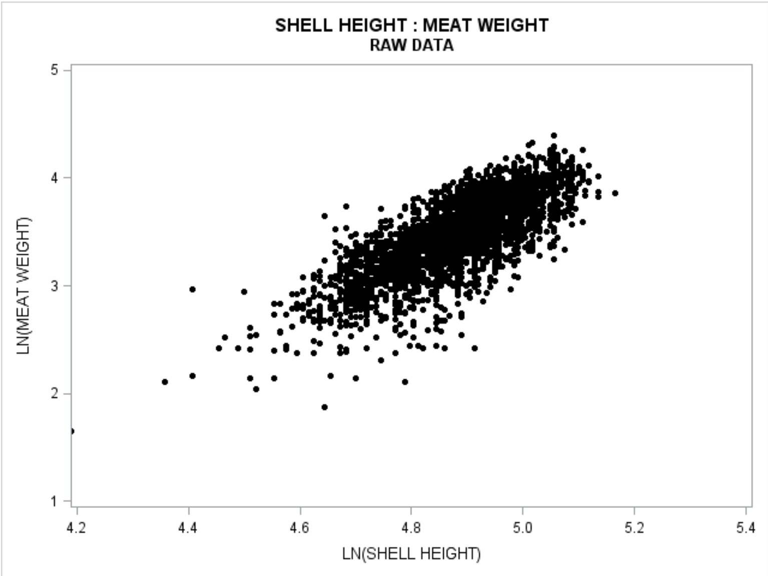


Figure E-2 Shell Height:Meat Weight data for all trips combined .

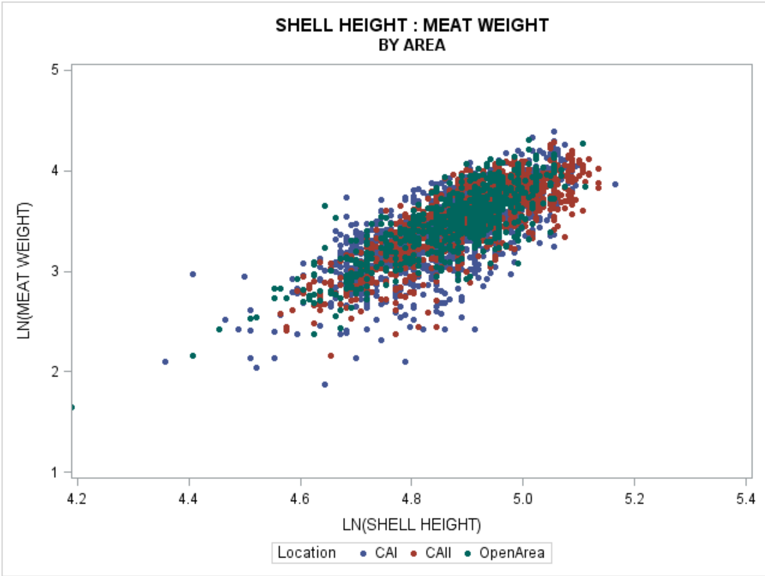


Figure E-3 Shell Height:Meat Weight data for all trips combined delineated by area (CAI, CAII, Open Area) .

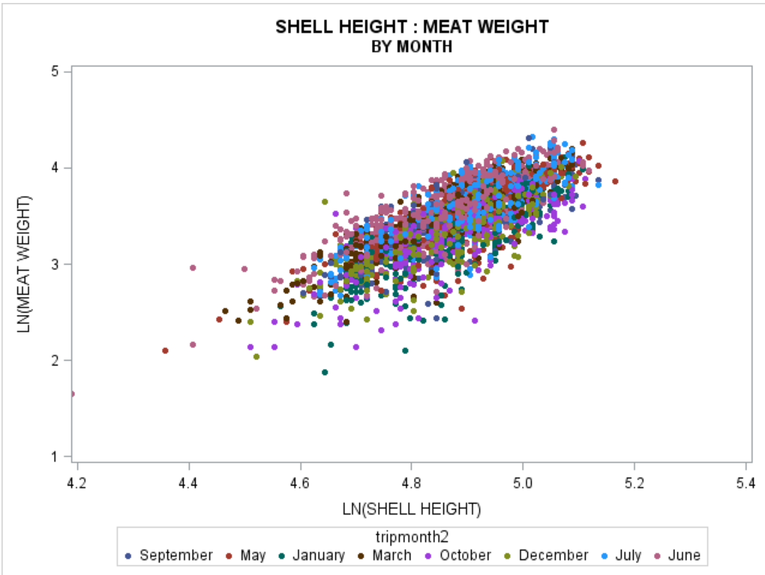


Figure E-4 Shell Height:Meat Weight data for all trips combined delineated by sampling month

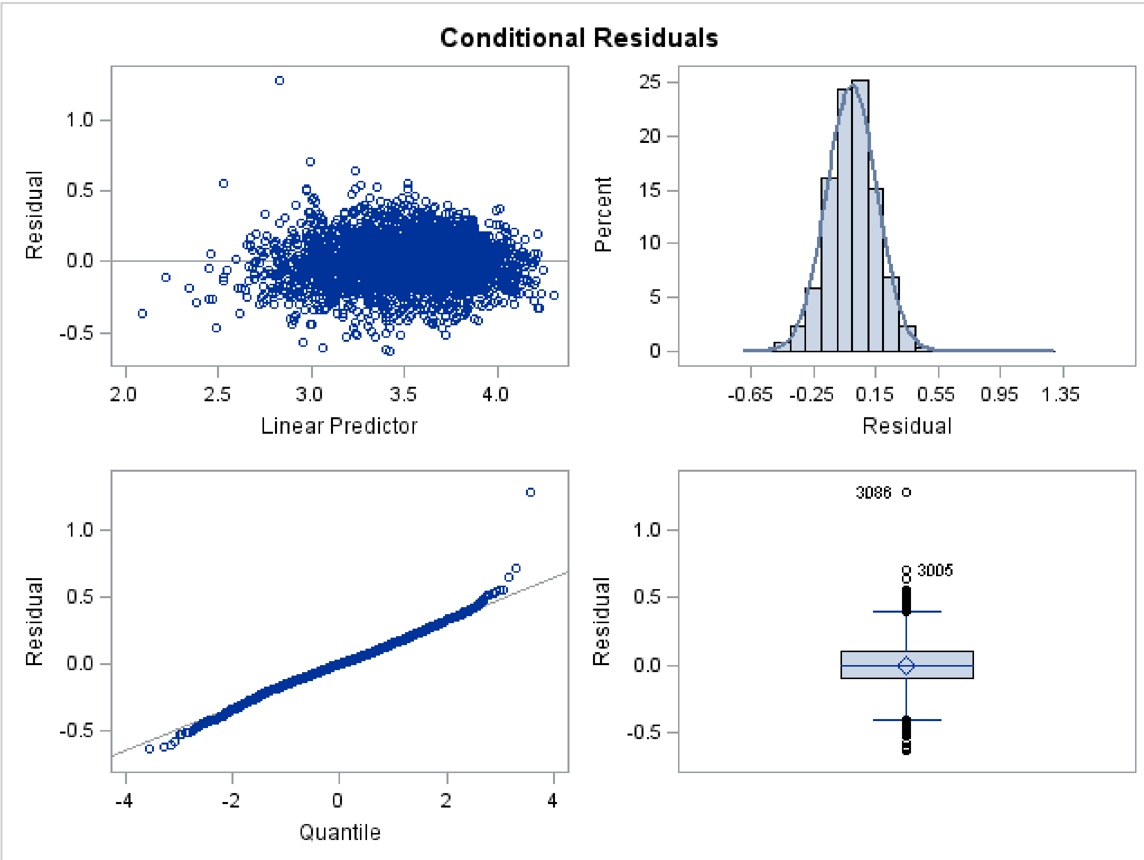
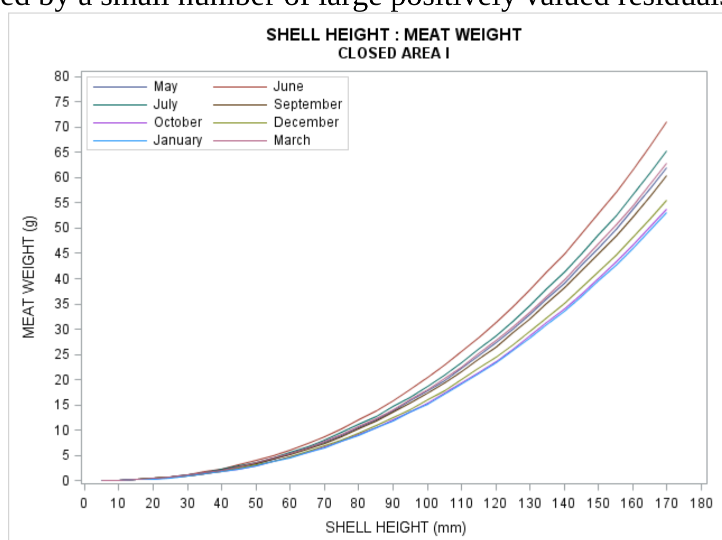


Figure E-5 Residuals and QQ plot for the best model fit as determined by minimum AIC value. Residuals show no evidence of pattern, however a number of larger than expected meats were observed as evidenced by a small number of large positively valued residuals.



<u>**Figure E-6**</u> Comparison of estimated curves for each month in Closed Area I.

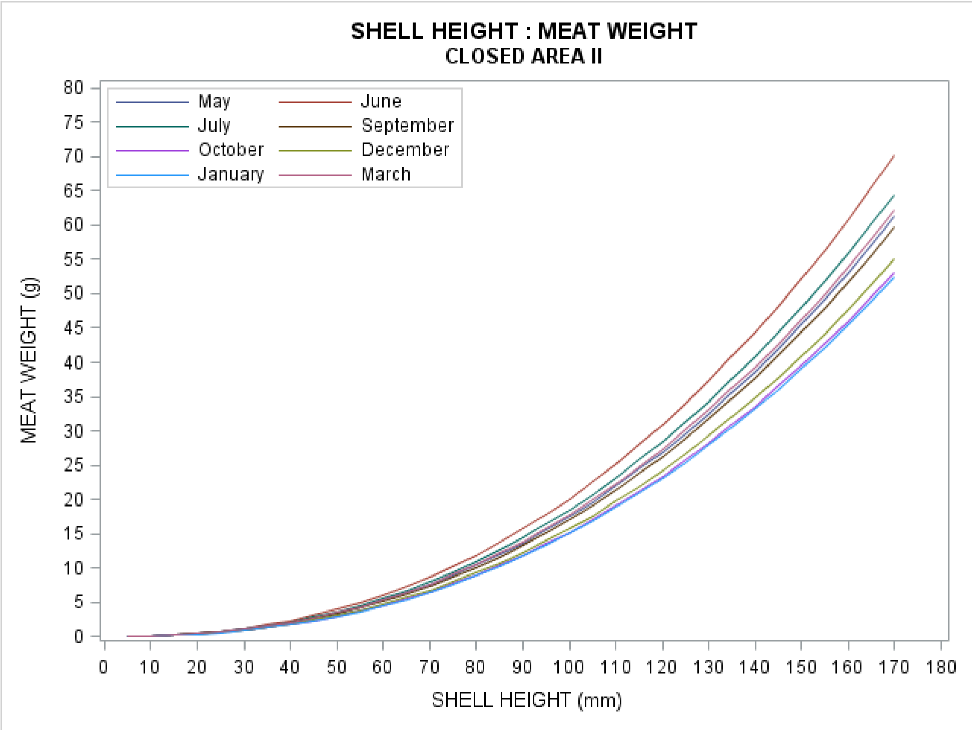


Figure E-7 Comparison of estimated curves for each month in Closed Area II.

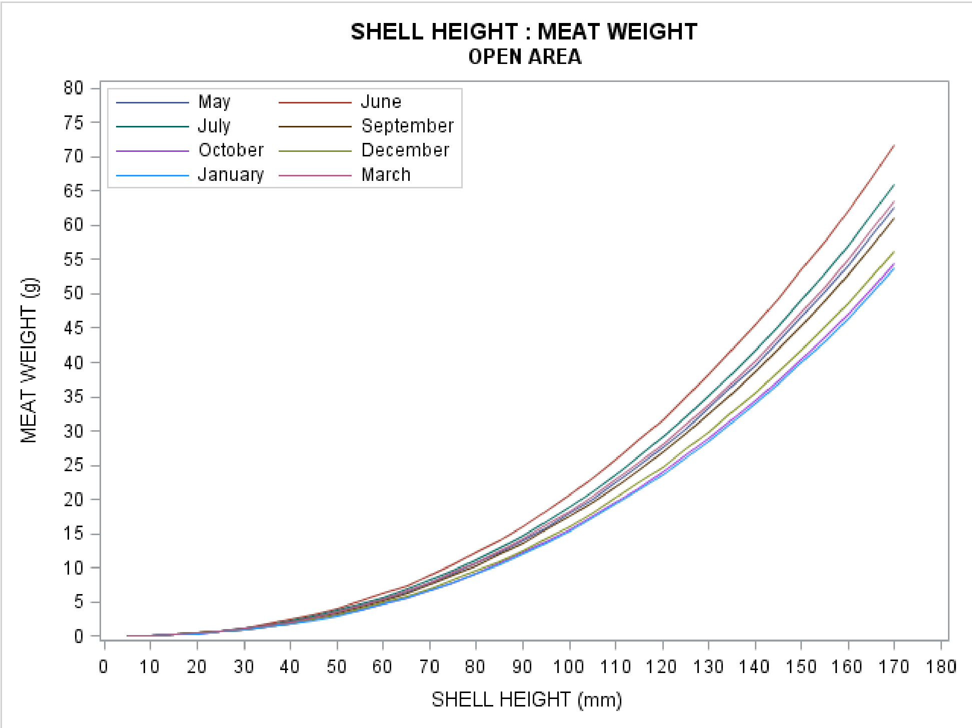


Figure E-8 Comparison of estimated curves for each month in Open Area

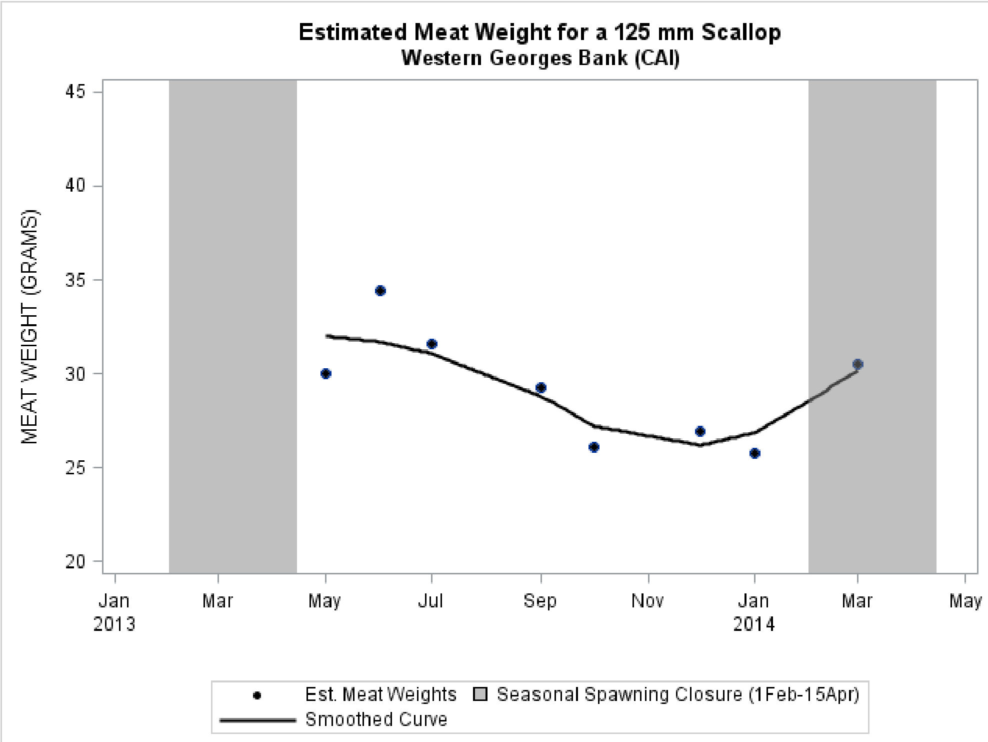


Figure E-9 Comparison of estimated curves for each month in Closed Area I.

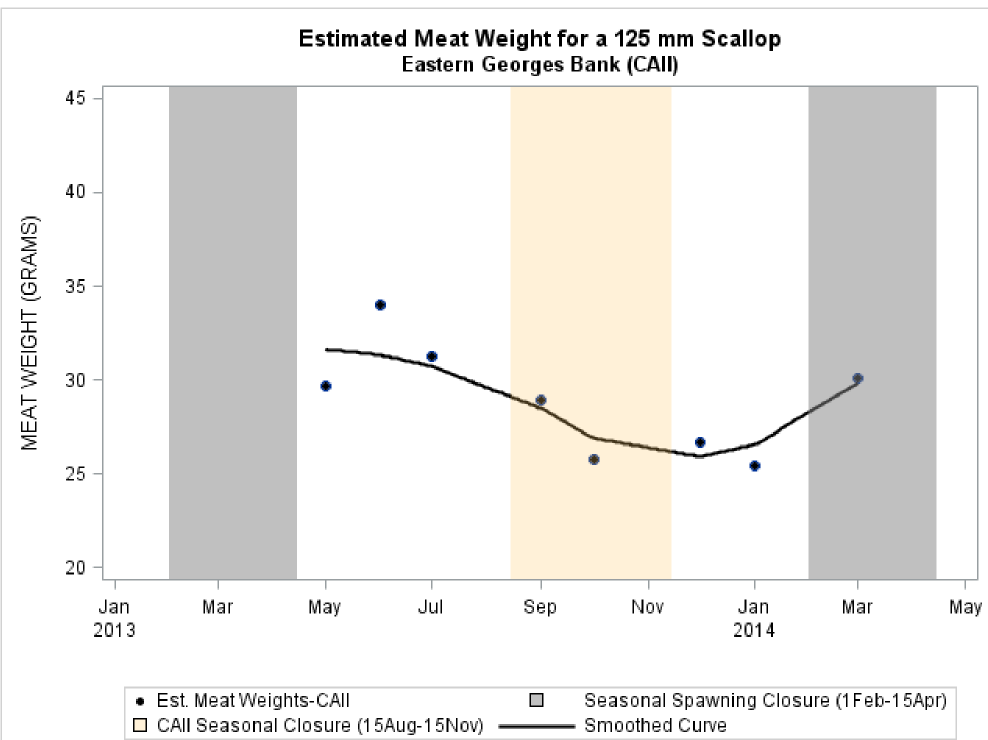


Figure E-10 Comparison of estimated curves for each month in Closed Area II.

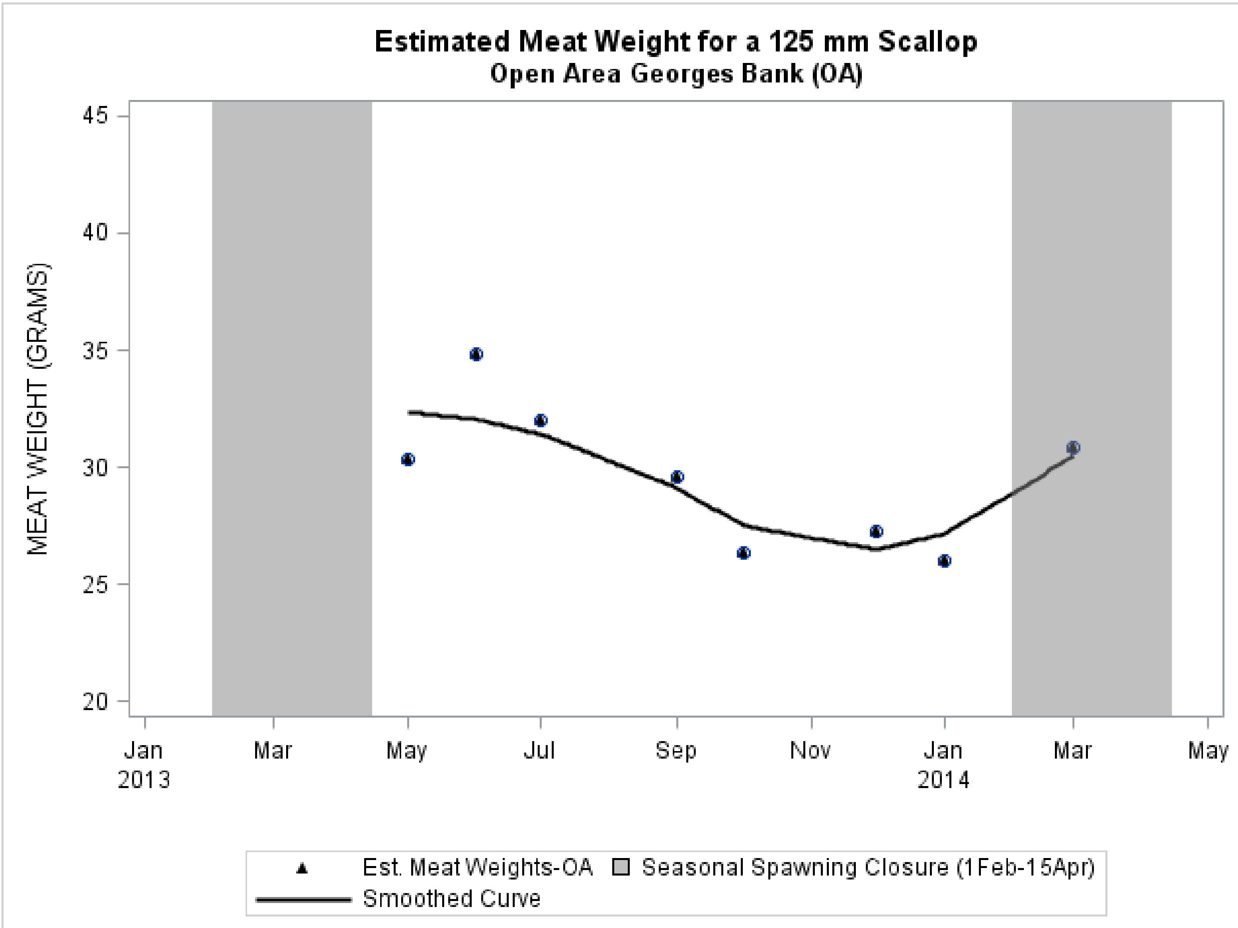


Figure E-11 Comparison of estimated curves for each month in Open Area.